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THE SUMMER SEASON ALONG THE EAST COAST OF HUDSON BAY DURING THE NINETEENTH CENTURY

PART III

Summer thermal and wetness indices
B. The indices, 1800 to 1900

by

C.V. Wilson

ATMOSPHERIC ENVIRONMENT SERVICE

DOWNSVIEW, ONTARIO

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THE SUMMER SEASON ALONG THE EAST COAST OF HUDSON BAY DURING THE NINETEENTH CENTURY

A sample study of small-scale historical climatology based on the Hudson's Bay Company and Royal Society Archives

PART III: Summer thermal and wetness indices
B. The indices, 1800 to 1900.

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C.V. Wilson

A publication of the Canadian Climate Program

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ABSTRACT

This report marks the completion of the last phase of a project to obtain thermal and wetness indices for the summer seasons (May to October) of the nineteenth century along the east coast of Hudson/James Bay. The series are based on weather and proxy weather data from the Hudson's Bay Company Post Journals, Correspondence and Annual Reports for Little Whale River, Great Whale, Fort George and Eastmain. The methodology was described in the previous report, Part III A (Canadian Climate Centre Report No. 85-3).

The thermal indices represent an estimate of the seasonal temperature anomaly with respect to the normal reference period 1941-1970 at Great Whale, Fort George and Eastmain. After a benign start to the century, the seasons became cooler, tumbling in a spectacular fall in 1816, 1817 to values far below the modern record. Seasons well below the 1941-1970 normal remained characteristic of the first half-century. A certain amelioration at mid-century was followed by some very cold weather in the 1860's, before a remarkably sudden change occurred in the early 1870's to a new higher energy level, akin to that at the beginning of the nineteenth century and to that today. Although not as warm as the 1870's, the last two decades of the century sustained these milder conditions. A breakdown of the season pointed to the relative coldness of the spring and autumn months and effective shortening of the active season. There was less difference between the mid-summer months and those today. The upward trend from 1811-1840 through 1871-1900 is very clear.

The wetness indices are based on the number of days with reported precipitation (supported by other weather and proxy information) with reference to the modern frequency distributions. The first half of the century was wetter, the second half drier than average. By far the wettest decade was 1811 to 1820. From 1850 dry seasons occurred with increasing frequency; the driest decades were 1871-1880 and 1891-1900. A seasonal breakdown shows some very wet springs in the first 50 years, and some very dry mid-summers and autumns in the latter half of the century.

This pattern of climatic change for the May-to-October season through the nineteenth century has no analogue in the present century on the east coast of the Bay.

RESUME

Le présent rapport marque la réalisation de la dernière phase d'un projet visant à obtenir les indices thermiques et d'humidité pour les saisons d'été (mai à octobre) du XIX^{e} siècle sur la côte est de la baie d'Hudson/James. Les séries reposent sur les données météorologiques, de substitution ou non, des revues des comptoirs de la compagnie de la baie d'Hudson, de la correspondance et des rapports annuels de Little Whale River, de Great Whale, de Fort George et d'Eastmain. On a décrit ces méthodes dans le rapport antérieur "Part III A" (Report No. 85-3, Centre climatologique canadien).

Les indices thermiques représentent une estimation de l'anomalie des températures saisonnières par rapport à la période normale de référence de 1941-1970 à Great Whale, Fort George et Eastmain. Après le temps doux du début du siècle, les saisons se refroidirent, en chutant de façon spectaculaire en 1816 et 1817, nettement au-dessous du relevé moderne. Les saisons bien inférieures à la normale de 1941-1970 restèrent caractéristiques de la première moitié du siècle. Une certaine amélioration, survenue au milieu du siècle, fut suivie par un temps glacial dans les années 1860-1870, avant le changement vraiment soudain du début des années 1870, qui fit remonter le niveau énergétique à un niveau semblable à celui du début du XIX^{e} siècle et à celui d'aujourd'hui. Les deux dernières décennies du siècle, même si elles ne furent pas si chaudes, qu'en 1870-1880, connurent ce radoucissement. La ventilation de la saison a révélé un temps assez froid pendant les mois du printemps et de l'automne et un raccourcissement effectif de la saison active. L'écart entre les mois du milieu de l'été était moins important qu'aujourd'hui. La tendance à la hausse, de 1811-1840 à 1871-1900 y compris est manifeste.

Pour la distribution moderne des fréquences, les indices d'humidité reposent sur le nombre de jours pour lesquels on a signalé des précipitations (données s'appuyant sur d'autres données météorologiques et des données de substitution). La première moitié du siècle fut plus humide que la moyenne, la seconde plus sèche. La décennie la plus humide est, de loin, celle allant de 1811 à 1820. A partir de 1850, il y eut de plus en plus de saisons sèches. Les décennies les plus sèches sont celles de 1871-1880 et de 1891-1900. Une ventilation saisonnière révéle quelques printemps très humides pendant les 50 premières années et quelques milieux d'étés et automnes très secs pendant la seconde moitié du siècle.

Cette configuration du changement climatique des saisons s'étant écoulées de mai à octobre au cours du XIX^{e} siécle ne se représente pas dans le siècle actuel sur la côte est de la baie.

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My thanks also to many people at the Atmospheric Environment Service and elsewhere, who have helped me in so many ways, and to the Hudson's Bay Company, without whose cooperation the study would not have been possible.

".....the present is the key to the past, but there have been many strange meteorological situations for which we have no present parallel to guide us."

C.E.P. Brooks. Climate through the Ages.
In the Preface to the First Edition, 1926.

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INTRODUCTION

A reading of the Hudson's Bay Company (HBC) Journals kept at the Posts along eastern Hudson/James Bay during the nineteenth century leaves a strong impression as to the quality of the different summer seasons (May to October.) The impression rests on the subtle integration of the many different weather and environmental factors remarked upon, and their impact. In this third phase of the study of nineteenth century summer climate along the east coast of the Bay, this rich variety of information has been used as a basis for the development of summer thermal and wetness indices. A methodology was described and applied to test periods in a previous report (Wilson, 1985a, Part III A); the results were encouraging. The thermal and wetness indices for this region are now complete for summers 1800 to 1900, and are presented here.

The experience on which these indices are based has been built up gradually through the two earlier phases of this project, and this report needs to be read in the context of the earlier findings (cf. Wilson, 1982, Part I; 1983a, Part II[1]). Part I includes a full introduction to the project and to the historical material, an analysis of the modern climate along this coast, a reconstruction of the historical sites of the HBC Posts in comparison with those of the modern weather stations, and a calibration of the temperature records for Great Whale[2], Fort George and Eastmain (1814 to 1821), bearing in mind differences in site, instrument type and exposure, and observing practices. Part II contains an in-depth study of the seasonal weather and climate, 1814 to 1821, for which both detailed weather diaries and Journal information are available. Not only is this period of extraordinary interest, encompassing as it does the eruption of Mount Tambora in 1815 and part of a double cycle of minimal sunspot activity, but it has served as a climatic benchmark in the early part of the century for the index study.

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[1] For convenience, the three previous reports will be referred to simply as Part I, Part II, Part III A. (See also Wilson, 1983b, 1985b.)

[2] Great Whale, later Poste-de-la-Baleine, and now Kuujjuarapik

THERMAL INDICES

THE APPROACH IN REVIEW

The aim was to estimate for the historical seasons the monthly temperature anomaly with respect to a modern reference period. The thermal index is a simple scale built around the 1941-1970 normal monthly temperatures for each site. Since Part III A was written, the form of the index has been modified slightly; this is discussed below. At different times during the century, and in differing combinations, HBC Posts were reporting at Eastmain, Fort George, Great Whale and Little Whale River. In the case of the first three sites, modern weather records are to hand; for Little Whale River, the nearest reference station is Great Whale, 96 km to the southwest, but with a similar exposure.

To gain a first approximation to the monthly temperature anomaly, the direct daily weather entries in the Post Journals for each month of the 'active' season (May to October) were evaluated against information for the period 1941-1970. Proxy weather indicators were then used as guidelines to obtain at best an order of magnitude (timing, intensity, duration), or at least supporting or modifying evidence. In seasons where Journals exist for more than one Post, each site was considered separately, and the results were then combined. The index thus depends on the integration and convergence of many kinds of evidence; variety of material helps to compensate for fragmentation.

In practical terms, some firm structure or anchor was required to accommodate so many kinds, fragments and combinations of data. A secure yet flexible modern frame of reference was provided by the envelope of daily temperature curves for Great Whale, Fort George and Eastmain, comprising for each day of the season the period daily mean, the highest and lowest daily mean, the mean and extremes of maximum and minimum temperature. Since the daily mean temperature averaged over a month conceals the variety and timing of temperature sequences (often critical in the interpretation of proxy data), the historical material was assessed by week, then "averaged" over the month. A further guide was provided by the weekly daily mean temperature for the reference period as well as the weekly means and frequencies of the maximum and minimum values.

Central to the analysis is the fact that the modern point of reference for all kinds of historical data is the air temperature (daily maximum and minimum) as recorded in a screen some 1.5 m above the ground at a particular site. The patchwork landscape of highly differentiated sites and surface conditions characteristic of this

subarctic coast, together with its openness to the west and north, and the presence of ice offshore or low Bay surface temperatures late into the season, can lead both to sharp spatial differences in small-scale climate and to extreme changes of weather within an hour, or so. In Part I, these key aspects of the climate were explored. As the HBC Journals often include regular reports on the winds, a synoptic climatology was set up to offer guidelines as to the relationship between temperature and wind direction, bearing in mind site and surface conditions on land and offshore.

On a longer time-scale the questions become:

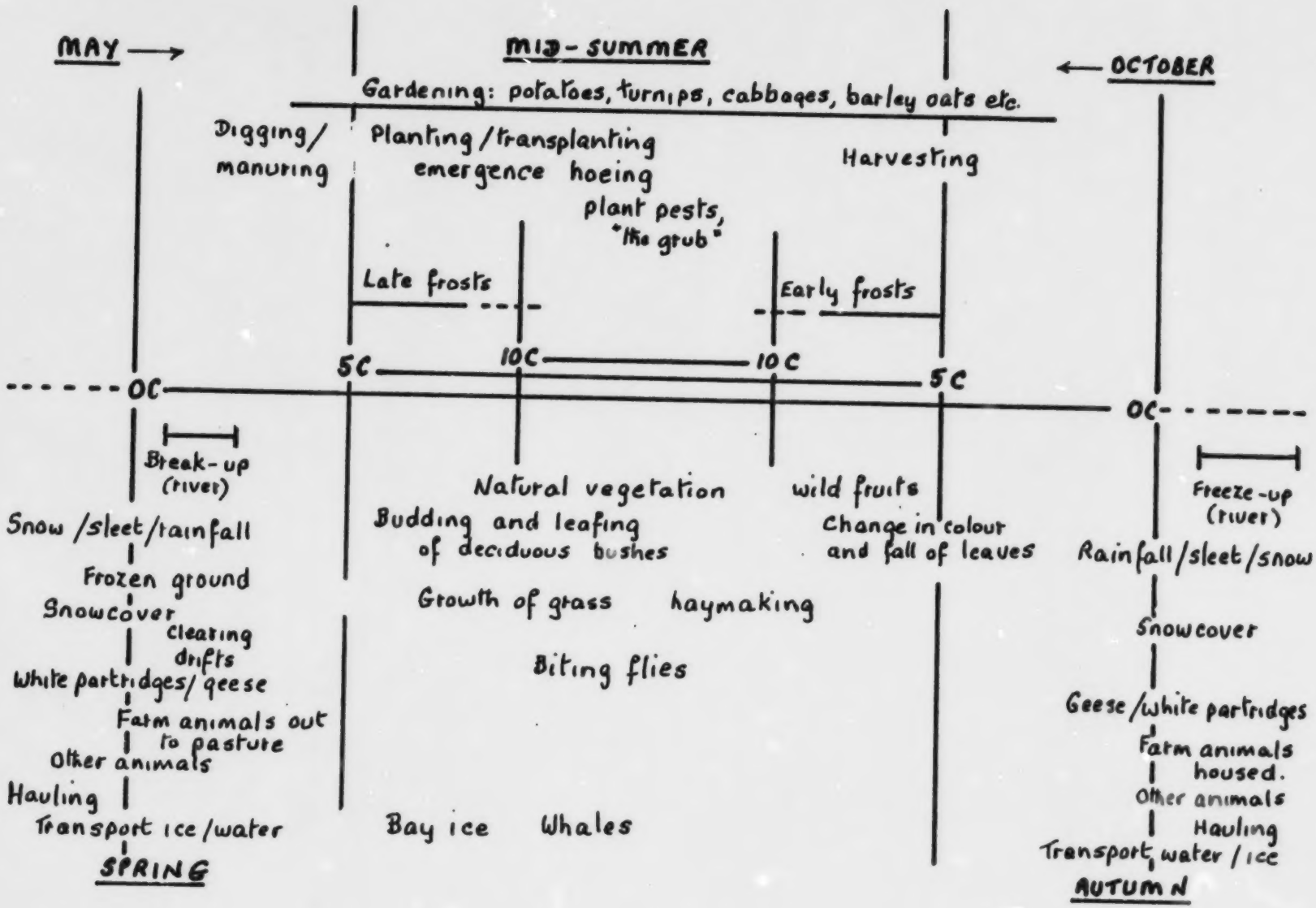
(i) What are the combinations of climatic controls that can lead to an abnormally warm or cold month, or season, at this time of year, along this coast?

(ii) Are there recognizable patterns to the frequency distributions of maximum and minimum temperatures and other weather elements in extreme months?

These questions were approached in Part I, and in Part II monthly analogues were described for Great Whale, Fort George and Eastmain, as a basis for the study of seasons 1814 to 1821. Both the modern analogues and those provided by this early period have been useful in assessing the degree of anomaly for the other summer seasons of the nineteenth century.

The kinds of proxy weather-related information in the HBC Journals are summarized in Figure 1. Much of this material refers to the spring and fall months, to the transition of the air temperature through 0C, with attendant change in phase and its impact on life and activities. The primary indicators are river ice, snowcover, and the snowfall/rainfall ratio and threshold. Sightings of birds and animals, hunting, trapping, and changes in forms of transport provide important supporting evidence. For the shoulder and mid-summer seasons, the proxy indicators are mostly plants and occasionally insects. The main sources of information are the vegetable gardens and haymaking at Fort George and Eastmain -- the garden operations, the progress of the crop, the harvest, the growth and quality of the grass, and the haymaking weather. Fortunately there are few seasons with Journals only for Great Whale or Little Whale River. Occasionally serious infestations of mosquitoes, horse- and sandflies are mentioned, or of the "grub", cutting down the potato plants. The greatest variability in the amount of proxy information from year to year is in July and August.

FIGURE 1. Summary of environmental indicators.



The approach to the proxy data was twofold:

(i) To try for a statistical link between the proxy data and the monthly temperature anomalies, to provide some rules of thumb.

(ii) To try to obtain some indication of the timing or magnitude of seasonal and unseasonable temperature events, and to compare where they intersect the modern daily or weekly curves. Included in this general approach is the use of cardinal points with respect to plant growth, and the heat unit concept. The latter combines the timing of the seasonal passage through certain key temperature thresholds (for example, 0C, 5C, 10C) and the corresponding degree-day accumulations. A useful variant on this is the idea of agroclimatic capability classes (Eley and Findlay, 1977), in which the crop potential of a location is delimited in terms of growing degree-days (base 5C), the frost-free period and a moisture index.

For a description of the guidelines for the use of this proxy information as an indication of air temperature, and for details of the procedures in assessing the thermal index, see Part III A. In addition, further clarification of the summer guidelines can be found in Appendix A of this report.

MODIFICATION OF THE INDEX

The original index (Table 1a) consisted of seven classes, from -III to +III, based on the deviation from the monthly temperature normal (1941-1970). The class interval was 2C. The centre of the scale, "0", ranged between -1C and +1C.

In practice, modification had slipped in out of necessity.

(i) The original class size proved too large to handle easily in assessing the degree of anomaly at a particular site, and intermediate (borderline) cases such as 0/+I, -I/-II, naturally came into use. (See for example, Part III A, Table 6.)

(ii) Again, when more than one Post was reporting in a season, and the results were to be combined, the large class size was not always sensitive enough.

(iii) The central values of the original classes were 0,2,4,6C, which was too widely spaced to allow a simple algebraic summation and averaging of the monthly anomalies as a measure of the seasonal value.

TABLE 1a. Thermal index, Original form. (The normal reference temperatures for Great Whale, Fort George, Eastmain are given in Table 5.)

Central Value °C	(-6)	-4	-2	0	+2	+4	(+6)
INDEX	-III	-II	-I	0	+I	+II	+III
Limits °C	⩾-5	-3 < -5	-1 < -3	<-1 to <+1	1 < 3	3 < 5	⩾5

(N.B. Class intervals expressed with reference to 0C.)

TABLE 1b. Thermal index, revised. Percentage of the monthly indices expected in each class, based on the normal curves for Great Whale, 1941-1970.

Central Value °C	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8
INDEX	-IV	-III/-IV	-III	-II/-III	-II	-I/-II	-I	0/-I	0	0/+I	+I	+I/+II	+II	+II/+III	+III	+III/+IV	+IV
Limits °C	-7.5/ -8.4	-6.5/ -7.4	-5.5/ -6.4	-4.5/ -5.4	-3.5/ -4.4	-2.5/ -3.4	-1.5/ -2.4	-0.5/ -1.4	+0.4/ -0.4	+0.5/ +1.4	+1.5/ +2.4	+2.6/ +3.4	+3.5/ +4.4	+4.5/ +5.4	+5.5/ +6.4	+6.5/ +7.4	+7.5/ +9.4
MAY %		<0.1*	0.4	1.25▲	3.5	7.25	12.5	17	16	17	12.5	7.25*	3.5▲	1.25	0.4	<0.1	
JUNE %		<0.25	0.65*	1.85	4	7.75▲	12.5	16	14	16*	12.5	7.75	4	1.85	0.65	<0.25	▲
JULY %			<0.1*	0.27	1.3▲	4.9	12.5	21	20	21	12.5*	4.9	1.3▲	0.27	<0.1		
AUG. %			<0.1	0.38*	1.8	5.5▲	12.25	20	20	20	12.25*	5.5	1.8▲	0.38	<0.1		
SEPT. %				<0.2	0.93*	3.9▲	12	23	20*	23	12	3.9	0.93	<0.2			▲
OCT. %		*	<0.1	0.64	2.1▲	5.75	12.5	20*	18	20	12.5	5.75▲	2.1	0.64	<0.1		

▲ Extreme anomalies of modern instrumental record 1916-1925 Fort George (broken), 1926-1983 Great Whale.

* Extreme anomalies of historical instrumental record (adjusted), 1844-1821, Great Whale, Fort George, Eastmain.

The classes were therefore adjusted to accommodate these needs, by reducing the interval to 1C. Table 1b shows the new class limits, together with the percentage of the monthly indices (May to October) that can be expected in each category based on the 1941-1970 normal curves for Great Whale. The rather cumbersome indicators to the classes reflect this history, and for the moment have been retained for convenience.

There is always the danger of trying to produce a finer resolution than the material will bear, but in this particular case, the halving of the interval does, I believe, reduce the error.

On the new scale, "0" ranges between -0.5C and +0.5C. The central values of the classes are now 0,1,2,3C and so on, and these have been added algebraically and averaged to give the bimonthly and seasonal estimates of the temperature anomaly.

CONFIDENCE LIMITS

Although it is not easy to ascertain confidence limits for the reconstructed temperature series, from the discussion presented below I believe that the seasonal values offer a good approximation to the actual temperature anomalies for the summers 1800 to 1900 -- perhaps even close to the error of the index itself (within ±0.5C). Should there have been a tendency to underestimate the temperature in spring or fall and to overestimate in mid-summer, these are compensating errors with respect to the season. The most reliable indices are those for 1815 to 1820.

Some of the factors that must be taken into consideration include the seasonal variation in the amount and kinds of historical information and the number of Posts reporting, the influence of certain weather types in assessing the indices, and the question of the consistency of the analysis. These are considered briefly, followed by a statistical view of the indices.

Seasonal variation in the data

With respect to data coverage, the seasons can be broadly grouped as follows:

(i) Excellent, 1815 - 1821. Weather diaries with regular entries two or three times a day, including thermometer records; supplemented by remarks in the Journals, Correspondence and Annual Reports, and very detailed proxy information. There are concurrent records for two Posts. During this period, the recording of weather information was accorded priority by the Hudson's Bay Company.

(ii) Good, 1806-1809, 1822-1823, 1828-1844, 1857-1900. Regular daily weather entries in the Journals and detailed proxy information. In the first three periods, only one Post, but the reporting was full and conscientious; from 1857 to 1900, generally two to three Posts, and with the odd exception the combined coverage was good.

(iii) Intermediate, 1845-1856. Weather entries less regular, but Journals still include a great deal of weather information as well as proxy data.

(iv) Least, 1800-1805, 1810-1814, 1824-1827. Little weather reporting, but good proxy data. One Post only.

The individual monthly indices, listed in Appendix B, Table B-1, have been classed according to reliability. The table also shows the Posts reporting. A detailed view of the weather data coverage was presented in Part I, Figure 2.

Within the season, more information is available for the spring (May, June) and late autumn (October), where the changes around 0C provide a precise point of reference, and many cross-checks can be used. Given the normal late disappearance of Bay ice and exposure to northerly and westerly winds, the period of oscillation around 0C may be prolonged well into June and even July. Most Posts seem to have had a thermometer and unseasonable late and early freezes were often reported as such. The gardens and vegetation also give clues to the timing of the passage through 5C and other thresholds.

In addition, in May and June the normal temperature curve rises very sharply along this coast, and the early or late arrival of spring can create very clear-cut monthly anomalies. Although the curve is more attenuated in autumn, winter often sets in very abruptly. When this occurs earlier than usual, this can again lead to a well-marked anomaly.

The variability about the 1941-1970 normal temperature (Table 1) is less in mid-summer and early fall (July to September). Unless there are extremes of heat or unusual frosts and falls of snow or sleet, or prolonged periods of cloudy, damp weather "off the Bay", it can be more difficult to gauge the degree of temperature as registered in the screen. The variety of proxy data is more limited. Progress of the crops (and, more rarely, vegetation) and the type of harvest are important in suggesting temperature thresholds and limits, and accumulations of degree-days, but due allowance must be made as gardens (and insects) are very much a function of microsite. The term "warm" is very relative.

Types of weather, in assessing the indices.

For certain weather situations, the daily or monthly temperature anomalies can be harder to assess.

(i) Meridional flow patterns - blocking situations. Where there are protracted runs of opposite extremes of weather, back to back, often crossing monthly boundaries, it is sometimes difficult to balance the degree of heat or cold within the month. This frequently occurs in May and June.

(ii) Clear northerly weather. When winds are relatively light and surfaces dry, significant small-scale differences in temperature build up from place to place and between the ground surface and the screen (cf. Part I). While the advected air may be cold and govern the maximum temperature recorded in an exposed screen, the clarity of the airmass permits large amounts of solar radiation to reach the surface, so that the perceived temperature depends very much on the location of the observer. The Posts at Great Whale and Little Whale River were more open to the winds, but those at Fort George and Eastmain, while facing the river on the north, were otherwise in a clearing in the bush and generally protected by pallisades. In particular, those gardens within the pallisades and behind the houses had favoured sun-trap situations.

(iii) Dry days, with changing sky conditions and variable winds from the land and Bay. Here, the daily maximum and minimum temperatures depend on the timing of the cloud cover or breaks in the cloud, the timing and direction of the wind changes and the Bay surface temperature. Where ice is still present offshore, there are modern and historical records (August 1816, Great Whale) of the air temperature falling by more than 25C in just over an hour with the onset of a Bay breeze.

Consistency of the analysis

During the course of the analysis through the century, spot-checks were made for consistency from time to time by re-assessing the monthly indices for previous seasons. "Borderline" months were re-evaluated after a lapse of time. Extreme seasons were cross-checked against historical and modern analogues.

In the discussion of confidence limits in Part III A (p. 25), I had suggested that once the series were complete, a "vertical" check on the indices may be obtained by studying the time series of key proxy seasons per se. This was not a useful idea. With any one type of

environmental indicator, the relationship to temperature is so complex. The validity of the present method rests exactly on the degree to which the integration of the many forms of information has succeeded, and in the convergence of the evidence.

A statistical view

Tables 2a and 2d show the actual frequency distributions of the basic monthly indices for the historical and modern periods. (See also Table 1b.)

Comparing the nineteenth and twentieth century frequencies by month (Tables 2a, b), the form of the distributions is remarkably similar. In May, the historical series is displaced by about -2C, in September and October by about -1C. For May and October, the number of occasions with positive anomalies is only about a half and a third, respectively, of those today.

By contrast, the historical distributions for July and August are shifted in the positive direction (by about +1C). In August, the frequence of occurrence of positive anomalies is slightly less for the nineteenth century, but in July, at 51.6%, it is 20% greater than the modern frequency, where the modal value is -1C. Unless there is strong supporting evidence, these July and August values must be questioned.

Considering the frequency of all the monthly indices over the season, Table 2c indicates the distributions for the first and last half of the century, for 1800-1900 and 1916-1983. The values for running 30-year periods through the century, together with the actual frequency for 1941-1970, are given in Table 2d. Both tables point to an unbroken trend in the reduction of cases of negative anomaly (and increase in the positive) from the early part of last century into the mid-twentieth. The distribution for 1871-1900, closely resembles that for 1941-1970. For most of the period 1800 to 1900, the central values of the distributions are quite stable between -2C and 0C, displaced by about -1 from the modern (Tables 1b, 2d). From 1811-1840 to 1861-1890, it is the frequency of the more extreme values which shifts to the right.

There is a small error inherent in the form of the index itself -- the difference between the index and the actual mean temperature. The distribution of this error for the bimonthly and seasonal values for Great Whale, 1926-1976, (Table 3), suggests that the use of the index introduces a small negative bias in the autumn, and positive in spring. Over the season, the error is negligible.

TABLE 2a. Monthly thermal indices. 1800-1900. Percentage frequency by month.

INDEX	-IV	-III/-IV	-III	-II/-III	-II	-I/-II	-I	0/-I	0	0/+I	+I	+I/+II	+II	+II/+III	+III	+III/+IV	+IV
MAY		1·1		2·1	9·5	16·8	28·4	7·4	16·8	1·1	7·4	7·4	2·1				
JUNE			1·1		8·5	10·6	17·0	14·9	13·8	18·1	8·5	6·4	1·1				
JULY			1·1		1·1	3·2	7·5	8·6	26·9	32·3	16·1	3·2					
AUG.				1·1	1·1	5·4	8·7	16·3	26·1	23·9	15·2	2·2					
SEPT.					2·2	17·4	17·4	20·7	20·7	14·1	5·4	2·2					
OCT.		1·1	2·1		12·8	16·0	22·3	14·9	20·2	6·4	4·2						

TABLE 2b. Monthly thermal indices. 1916-1983. Percentage frequency by month (Fort George-Great Whale).

INDEX	-IV	-III/-IV	-III	-II/-III	-II	-I/-II	-I	0/-I	0	0/+I	+I	+I/+II	+II	+II/+III	+III	+III/+IV	+IV
MAY				1·5	1·5	11·9	10·5	14·9	22·4	11·9	14·9	6·0	4·5				
JUNE						7·7	18·4	15·4	16·9	15·4	10·8	10·8	3·1				1·5
JULY					3·0	7·6	9·1	27·3	21·2	19·7	4·5	6·1	1·5				
AUG.						3·0	14·9	19·4	16·4	23·9	10·4	9·0	3·0				
SEPT.						6·5	11·3	25·8	27·4	22·6	4·8				1·6		
OCT.					1·6	6·3	17·5	23·8	17·5	17·5	11·1	4·7					

TABLE 2c. Percentage frequency of all monthly indices for 1800-1850, 1951-1900, 1800-1900 and 1916-1983.

INDEX	-IV	-III/-IV	-III	-II/-III	-II	-I/-II	-I	0/-I	0	0/+I	+I	+I/+II	+II	+II/+III	+III	+III/+IV	+IV
1800-1850		0·7	1·4	1·0	8·9	10·6	16·4	13·0	20·6	14·7	10·3	2·4					
1851-1900					2·6	12·7	17·5	14·6	20·9	17·2	8·6	4·8	1·1				
1800-1900		0·4	0·7	0·5	5·9	11·6	17·0	13·7	20·7	15·9	9·5	3·6	0·5				
1916-1983				0·2	1·0	7·2	13·6	21·0	20·3	18·5	9·5	6·2	2·1		0·2		0·2

TABLE 2d. Monthly thermal indices. Percentage frequency of all monthly indices for running 30-year periods 1800-1900, and for Great Whale 1941-1970.

INDEX	%-ve	-V	-III/-IV	-III	-II/-III	-II	-I/-II	-I	0/-I	0	0/+I	+I	+I/+II	+II	+II/+III	+III	+III/+IV	+IV	%+ve
1801-1830	47·4		1·1	1·7	1·7	8·0	8·0	15·5	11·4	20·0	18·3	11·4	2·9						32·6
1811-1840	61·5		1·2	2·4	1·8	11·4	13·9	16·9	13·9	18·7	12·6	6·6	0·6						19·8
1821-1850	60·9			0·6	0·6	9·6	13·3	19·9	16·9	19·3	10·2	8·4	1·2						19·8
1831-1860	59·6			0·6	0·7	9·3	15·9	17·9	15·2	16·6	10·6	10·6	2·0	0·6					23·8
1841-1870	56·5					6·5	16·2	18·2	15·6	15·6	13·0	10·4	3·9	0·6					27·9
1851-1880	49·3					3·3	15·8	18·4	11·8	16·5	16·5	10·5	5·9	1·3					34·2
1861-1890	48·2					3·0	12·5	19·4	14·3	22·0	14·9	8·3	6·0	0·6					29·8
1871-1900	41·9					1·7	9·2	16·1	14·9	24·1	19·5	8·1	5·2	1·2					34·0
1941-1970	39·5				0·5	0·6	5·6	11·7	21·1	26·1	18·9	8·9	5·0	0·6		0·5		0·5	34·4

TABLE 3. Percentage frequency of the basic error in the thermal index (i.e. difference between the temp. values based on index classes and the true bi-monthly and seasonal means), Great Whale, 1926-1976.

INDEX ERROR °C	-0·5	-0·4	-0·3	-0·2	-0·1	0	+0·1	+0·2	+0·3	+0·4	+0·5
MAY/JUNE	3·9	3·9	3·9	5·9	23·5	9·8	21·6	21·6	5·9		
JULY/AUGUST			9·8	19·6	17·6	11·8	9·8	11·8	11·8	7·8	
SEPT./OCT.	2·0	5·9	3·9	29·4	15·7	9·8	7·8	17·7	3·9	3·9	
SEASON			2·0	15·7	27·4	31·3	19·6	2·0	2·0		

Conclusions

In the case of spring and autumn, there is strong supporting evidence of unusual cold. However, it is still possible that the mean temperature may on occasion have been underestimated. With the revision of the form of the index, the upper limit of index - I changed from -1C to -1.5C, and for -II from -3C to -3.5C. Indices were re-checked for consistency, but with borderline cases some error might also have crept in here.

The overestimate of some mid-summer temperatures is, I think, real. For reasons noted above, July and August were often more difficult to define, unless marked by extremes of weather; and this was much less frequent than in the case of spring and autumn. In some seasons the gardens had to be relied upon as an overall indicator of the amount of heat energy received. Potatoes are marginal to Fort George and Eastmain, unless on a favourable microsite or in a favourable season without sharp frosts. For example, a growing season may have begun late, yet a reasonable crop was obtained, which might suggest in the absence of contrary evidence a rather warmer than normal July or August. This may well have led to overestimates, given the importance of small-scale climate along this coast. On the other hand, there is no overwhelming evidence among the data that these mid-summers in question were particularly unfavourable. Any resulting error in the monthly index is perhaps not more than +1C-- one class.

The index is most reliable over the season, in which the errors act to compensate. Even if an outstanding error of as much as 2C were accumulated, the seasonal temperature anomaly would be changed by only 0.3C, still within the limits of the basic error in the index.

THE RECONSTRUCTED TEMPERATURE SERIES, 1800-1900

The series of seasonal temperature anomalies for the nineteenth century is plotted in Figure 2. Figure 3 and Tables 4 and 5 show the frequency and mean values for different periods within the century. For comparison, the respective modern series have been included (See also Part II, pp. 15-20; Figures 2 and 3.) The bimonthly anomalies are illustrated in Figures 4a-c. All the series are listed in Appendix B, together with the monthly indices.

May to October

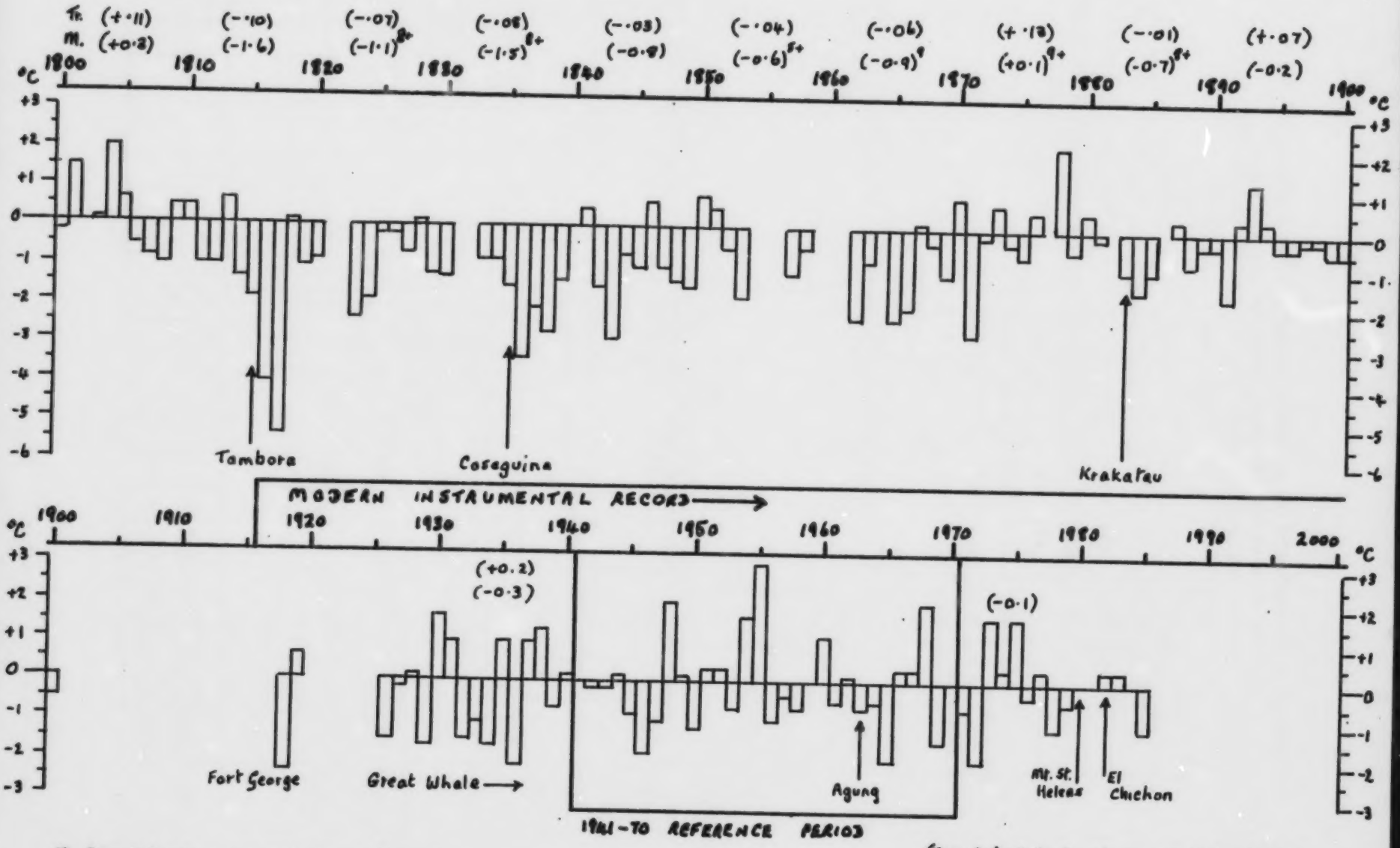
Following a very benign beginning to the century, the seasons became cooler, tumbling in a spectacular fall in 1816 and 1817 to values far below the modern record. Seasons well-below the 1941-1970 normal remained characteristic of the first half century, with a cluster of very cold years from 1835 to 1840. For 1801 to 1850, the May-to-October period probably averaged about 1C below that today; in the 1810-20 and 1830-40 decades, the anomaly was closer to -1.5C. A certain amelioration at mid-century was followed by some very cold weather in the 1860's, before a remarkably sudden change occurred in the early 1870's to a new higher energy level, akin both to that at the beginning of the nineteenth century and to that today. Although not as warm as the 1870's, the last two decades of the century sustained these milder conditions, and variability remained well within that for 1941-1970.

This upward trend in temperature from 1816/1817 to the 1870's (Figures 2 and 3, Tables 4 and 5) is reflected in the steady decline in the degree of severity of the coldest seasons, 1816, 1817, 1836, 1838, 1843 and 1871. Although there were runs of very cold years, only these six were more severe than those on modern record, with a further three (1823, 1862, 1865) beyond the 1941-1970 range. The greatest seasonal anomaly recorded in the reference period is positive rather than negative -- the exceptionally warm season of 1955. Although there appear to have been few positive anomalies in the nineteenth century as a whole, the two warmest seasons, 1878 and 1804 were similar to those of 1948 and 1968.

The timing of major volcanic eruptions is indicated on Figure 2. In the case of Tambora and Coseguina, the eruptions were followed by extreme cold, but the decline had clearly set in before these major volcanic events. For Krakatau and Agung, the "signal" is weaker, and with Mount St. Helens, absent. With El Chichon (1982) in mind, the temperature data for 1984, 1985, have been added. The eruption does not appear to have been associated at Great Whale with any immediate cooling for the season as a whole; the May-to-October temperature was below normal in 1985.

Figure 2 also shows the decadal anomalies in Parker's (1981) maximum density tree-ring series for Cri Lake (Great Whale), for comparison with the reconstructed temperature anomalies. The tree-ring anomalies are also with reference to 1941-1970. The correspondence at this level is encouragingly close. This relationship is also seen when comparing Figure 2 and Guiot's smoothed curve of Parker's indices

FIGURE 2. East coast Hudson / James Bay. Reconstructed temperature anomalies, °C, summer seasons (May to October) 1800 to 1900.



M. Decadal mean; superscript, no. of years
Tr. Maximum tree-ring density, decadal mean anomaly (Parker et al., 1981).

(For tabulated values, see Appendix B, Table B-3a, b.)

FIGURE 3. Reconstructed temperature anomalies: relative frequency of the seasonal values 1800-1850, 1851-1900 and 1926-1983.

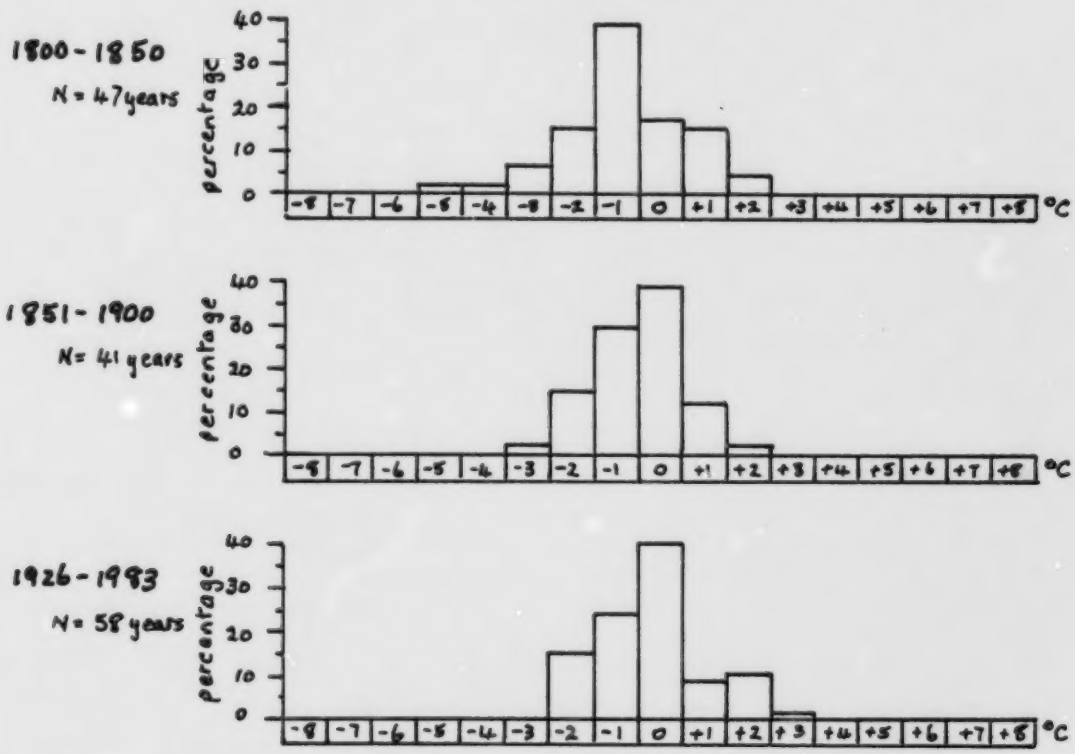


TABLE 4. Reconstructed temperature anomalies: frequency of the seasonal values, running 30-year periods (in number of years).

PERIOD / °C	-8	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	+8	No. of YEARS
1801-1830				1	1		3	11	6	4	2							28
1811-1840				1	1	2	5	11	5	1								26
1821-1850						3	6	10	4	3								26
1831-1860						3	5	10	1	4								23
1841-1870						1	6	9	3	5								24
1851-1880						1	4	7	5	5	1							23
1861-1890						1	4	7	9	4	1							26
1871-1900						1	2	7	13	3	1							27
1931-1960							4	8	10	5	2	1						30
1941-1970							3	9	13	1	3	1						30
1951-1980							3	9	12	1	4	1						30

TABLE 5. Decadal and period temperature anomalies, °C, 1801-1900, 1921-1980.

DECADE	M/J	J/A	S/O	Season
1801-1810	0·0	+0·9	0·0	+0·3
1811-1820	-1·8	-0·5	-2·4	-1·6
1821-1830	-1·7[9]	-0·1[9+]	-1·4[9]	-1·1[8+]
1831-1840	-2·1[9]	0·0[8]	-2·5[8+]	-1·5[8+]
1841-1850	-1·9	+0·4	-0·8	-0·8
1851-1860	-0·8[6+]	+0·1[6+]	-1·2[7]	-0·6[5+]
1861-1870	-0·6[9]	-0·4[9]	-1·6[9]	-0·9[9]
1871-1880	+0·3	+0·3[9]	-0·5	+0·1[9+]
1881-1890	-0·5	+0·1[9+]	-1·6[8+]	-0·7[8+]
1891-1900	-0·5	+0·8	-0·8	-0·2

DECADE	M/J	J/A	S/O	Season
1921-1930	-0·5[8+]	-0·9[8+]		
1931-1940	-0·7	+0·3	-0·4	-0·3
1941-1950	-0·3	-0·5	-0·2	-0·3
1951-1960	+0·5	+0·6	-0·2	+0·4
1961-1970	-0·4	-0·4	-0·0	-0·2
1971-1980	+0·5	+0·1	-0·8	-0·1

N.B. Fort George 1921-1925
Great Whale 1926-1980

PERIOD	M/J	J/A	S/O	Season
1801-1830	-1·1[29]	+0·2[29]	-1·3[29]	-0·7[25]
1811-1840	-1·8[28]	-0·1[27]	-2·1[27]	-1·4[24]
1821-1850	-1·9[28]	+0·1[27]	-1·5[27]	-1·1[26]
1831-1860	-1·8[25]	+0·2[24]	-1·5[25]	-1·0[23]
1841-1870	-1·3[25]	+0·1[25]	-1·2[26]	-0·8[24]
1851-1880	-0·4[25]	0·0[24]	-1·1[26]	-0·5[23]
1861-1890	-0·3[29]	0·0[27]	-1·2[27]	-0·5[26]
1871-1900	-0·2	+0·4[28]	-0·9[29]	-0·3[27]
1801-1850	-1·5[48]	+0·2[47]	-1·4[47]	-0·9[46]
1851-1900	-0·4[45]	+0·2[43]	-1·1[44]	-0·5[41]
1801-1900	-1·0[93]	+0·2[90]	-1·3[91]	-0·7[87]

(Superscripts: number of years.)

PERIOD	M/J	J/A	S/O	Season
1921-50	-0·4[28]	-0·3[25]	-0·2[25]	-0·3[25]
1931-60	0·0	+0·1	-0·3	-0·1
1941-70	0·0	0·0	0·0	0·0
1951-80	+0·3	+0·1	-0·3	0·0
1931-80	0·0	0·0	-0·3	-0·1

NORMAL REFERENCE TEMPERATURES				
PERIOD	M/J	J/A	S/O	Season
G.W. 1941-70	3·6	10·5	4·9	6·3
F.G. 1941-70	5·7	11·8	5·5	7·7
EM. 1960-72	7·4	12·7	7·2	9·1
(1951-80)	(6·2)	(13·4	(6·5)	(9·4)

(N.B. For monthly reference values, see Appendix B, Table B-2.)

(Guiot, 1986, p. 18). Jacoby et al.[3], in a recent study to reconstruct an historical temperature series for Great Whale from tree-ring data, found that maximum late-wood density was the best predictor of May through September mean temperature.

May/June, July/August, September/October

Figures 4a-c permit a breakdown of the season into spring, mid-summer and autumn. The most striking feature is the coldness of the spring and autumn months - the effective shortening of the active season during much of the century. The pattern of change in the spring series closely parallels that of the season as a whole, with mild seasons in the first decade and from the early 1870's, when the frequency distribution resembles that of today. In the autumn, cold seasons persist through the last two decades, although at this late period not below the 1974 record low. For May/June, the coldest decades from 1810 to 1850 probably approached 2C below the present; in September/October, 1810-1820 and 1830-1840 may have averaged as much as 2.5C below. This high frequency of very cold spring and fall months is supported by evidence of exceptional snowfalls, falls late and early in the season and late disappearance and early formation of river ice and snow cover.

The situation is quite different with respect to mid-summer (Figure 4-b). Even if it is accepted that there may have been some overestimation of the degree of warmth, it is evident that the July/August temperatures were in general not so very different from those today. The mid-summers of 1816 and 1817 remain in a class by themselves. Extremely cold seasons also occurred in 1836 and 1871, but were probably no colder than that of 1965. Potatoes, turnips and other vegetables were planted quite regularly at Fort George and Eastmain, and the number of seasons with no crop or a very poor crop was relatively few.

Considering the volcanic eruptions with respect to the bimonthly series, colder springs and autumns occurred around the time of the three major events in the nineteenth century, and, in 1816, 1817 and to a lesser extent 1836, very cold summers. In the modern series, the timing of Agung is interesting with respect to the exceptionally cold summer and autumn of 1965. The autumn of the year of the eruption of Mount St. Helens and the following spring were very cold. The midsummers following El Chichon, 1982 and 1832, were below normal. But it is the 1985 season which is remarkable as the coldest autumn on modern record at Great Whale -- October anomaly -8.2C. The mid-summer was also below normal: in July by as much as -4C.

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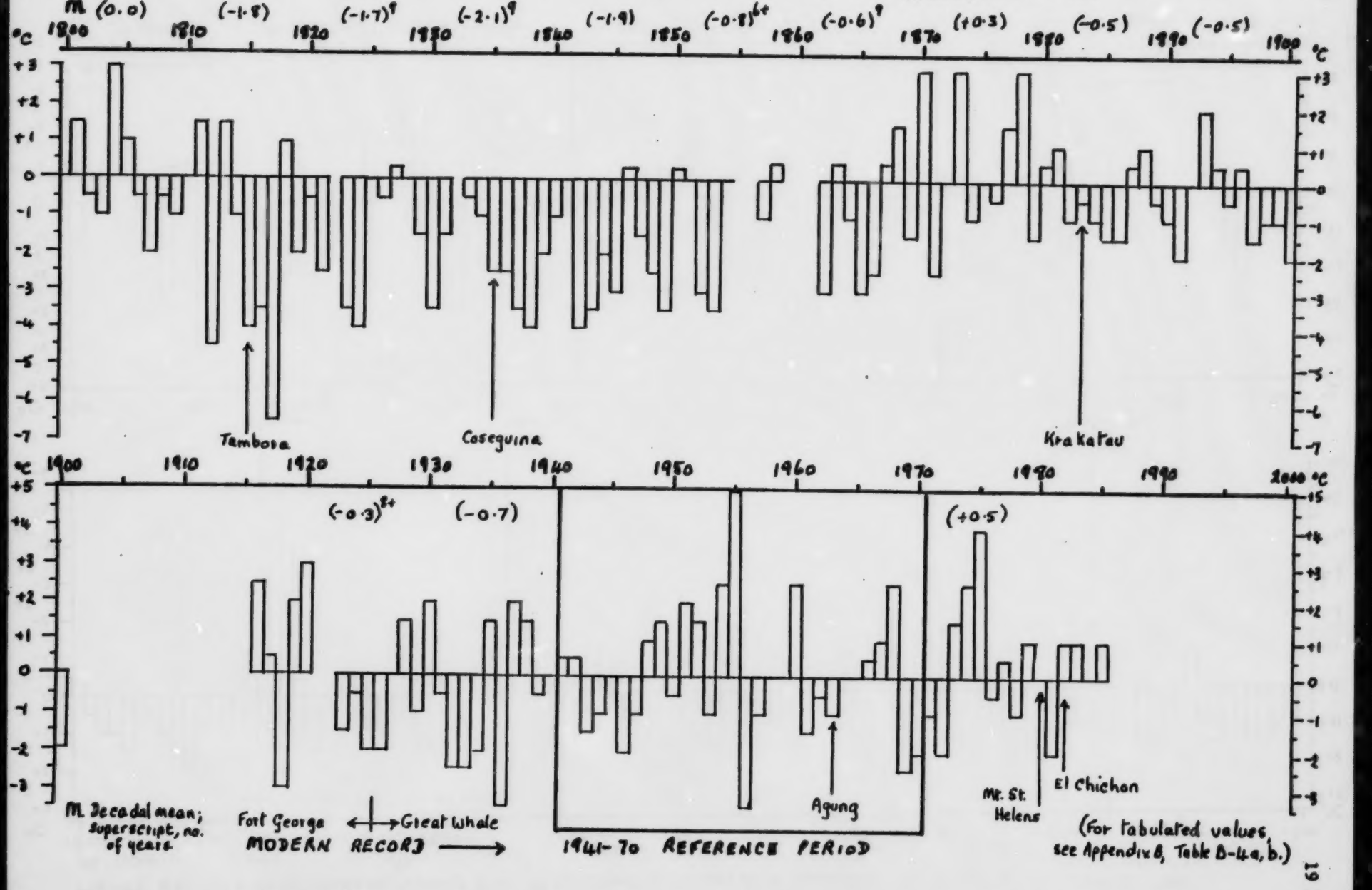
[3] I am grateful to Gordon Jacoby of the Lamont-Doherty Geological Observatory, Pallisades, N.Y., for sending me a copy of this unpublished work.

FIGURE 4a. East coast Hudson/James Bay. Reconstructed temperature anomalies, °C, May/June, 1800 to 1900.



M. Decadal mean; superscript, no. of years

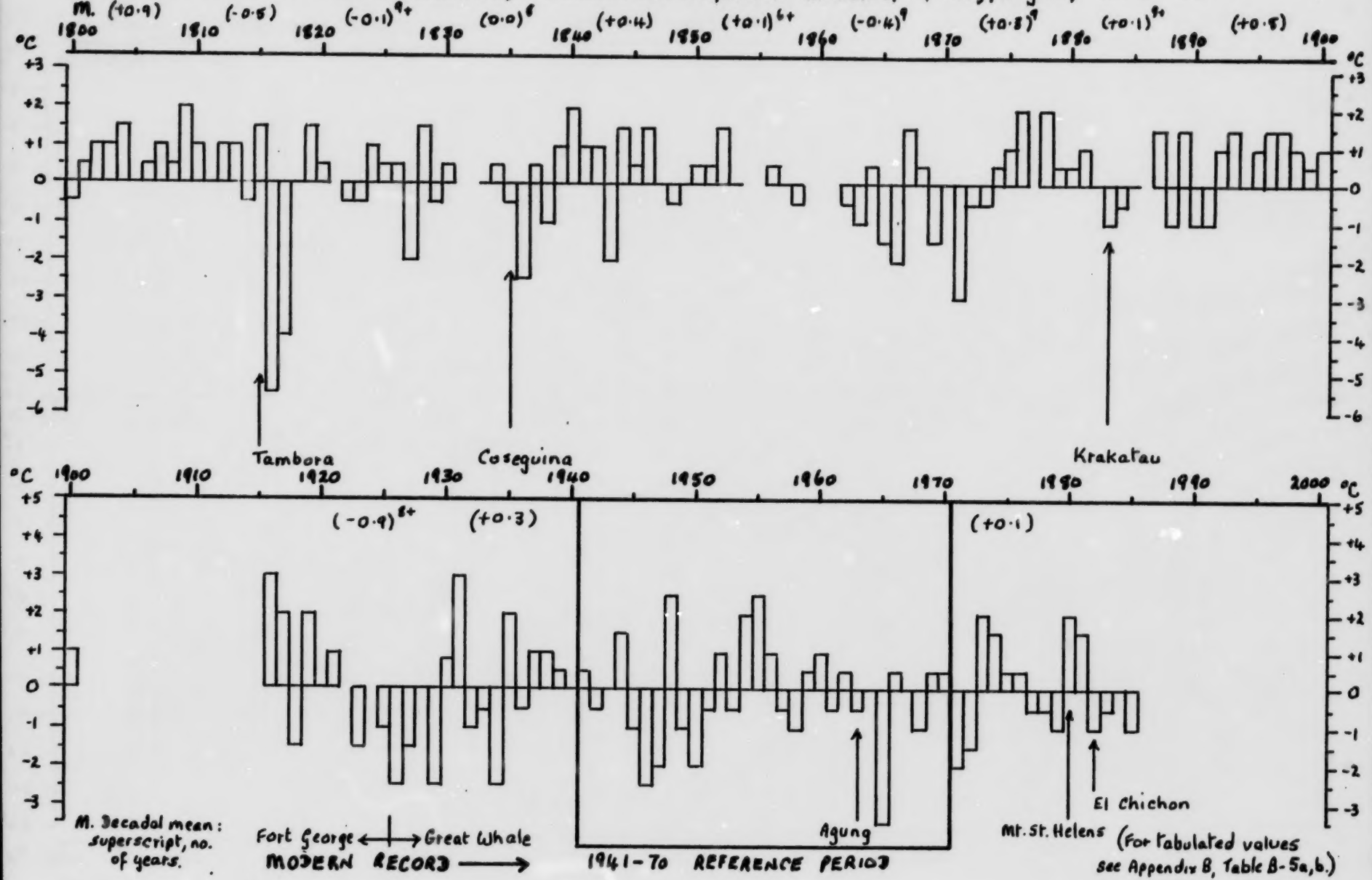
Fort George ←→ Great Whale

MODERN RECORD →

1941-70 REFERENCE PERIOD

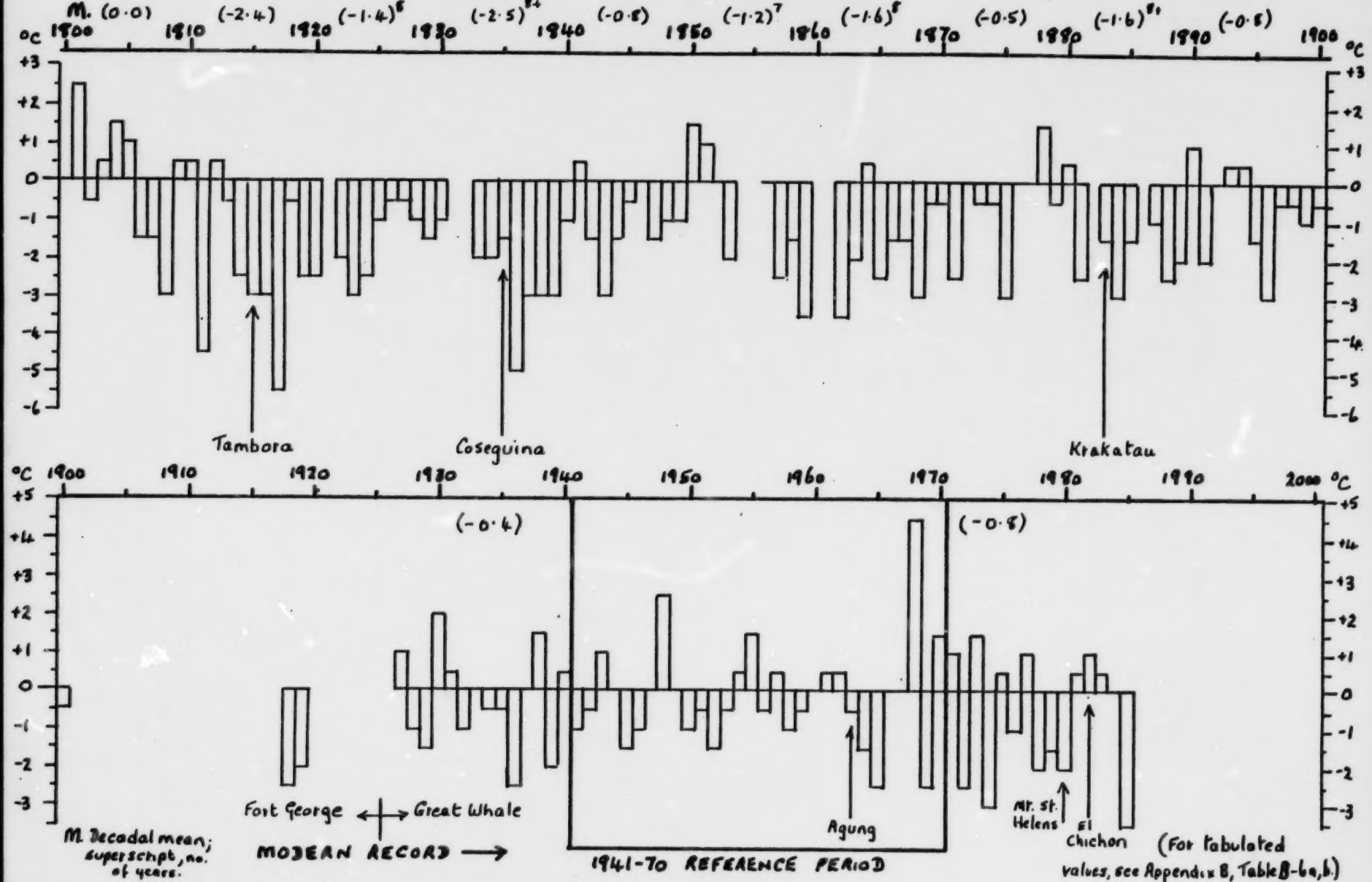
(For tabulated values, see Appendix B, Table B-4a, b.)

FIGURE 4b. East coast Hudson/James Bay. Reconstructed temperature anomalies, °C, July/August, 1800 to 1900.



(For tabulated values see Appendix B, Table B-5a,b.)

FIGURE 4c. East coast Hudson/James Bay. Reconstructed temperature anomalies, °C, September/October, 1800 to 1900.



The next step is to study these series of temperature anomalies more closely in relation both to Parker's tree-ring series for Cri Lake and to the two independent temperature reconstructions that have now been made for Great Whale. That of Jacoby et al. is based on a combined tree-ring width-density index, which explained a higher proportion of the variance than either width or density alone. The resulting mean temperatures are for June through August. Likewise, Guiot's summer series, based on a variety of climate and proxy data, covers the period June to August. To allow direct comparison, the mean temperature anomalies, June-August, based on the historical indices are illustrated and listed in Appendix B (Figure B-1, Table B-7), although the degree of confidence is less than for the May-to-October values. With the addition of the spring month, June, to the mid-summer anomalies, this new series shifts towards the broad patterns of temperature change through the nineteenth century seen in the seasonal May-to-October means, in which the May/June months were a major contributor.

WETNESS INDICES

Like the thermal indices, the wetness indices for each year were assessed directly with respect to the modern reference period. The reference in this case is the entire precipitation record up to 1976, at Great Whale (1926-1976), Fort George (1916-1969) and Eastmain (1960-1976). A general discussion of the nature of the historical precipitation data and some of the problems which arise in using them as a basis for a wetness index was presented in Part III A (pp. 29-34).

The basic information in the HBC Journals for comparison with modern data is the number of days with precipitation by month and for the season as a whole. In modern times, a day with precipitation is defined by measurement -- a 24-hour period with at least 0.2 mm of rain (or water-equivalent), or 0.2 cm of snow. Except for unusually heavy snowfall, the amount of precipitation was not measured at the HBC Posts. As a result, the underlying problem is the possible underestimate of the historical count. Two reasons for this are the occurrence of precipitation at night, and the varying degrees of interest, conscientiousness and motivation on the part of the observers and writers of the Journals.

The historical records of precipitation depended largely on sight and sound. If a fall occurred only at night, it may not have been perceived. With late spring and early autumn snowfall, night occurrences were often indicated by the presence of fresh or new snowcover the following morning, which aroused enough interest to be noted. When rainfall at night was sufficiently heavy or driving to be heard, it too was generally reported in the Journal next morning. Along this coast, however, much rainfall can be light or drizzle, yet more than a trace, and had it occurred at night, either not noticeable or unworthy of comment.

Snowfall measurement remains a problem today. Manley (1978), following Ashmore (1952) showed that large discrepancies can arise between 24-hourly reporting stations and neighbouring climatological stations (2 observations a day) in the recorded number of days with snowfall, for northerly maritime locations. He concluded that such first-class weather stations can report as many as twice the number. A study of five months of concurrent observations for Great Whale airport and a nearby climatological station indicated that the airport record was greater by a factor[4] of about 1.4. This would

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[4] For annual snowfall counts at Scottish and Northern England stations, Manley's regression equation was A = 1.3C +6, where A is the airport and C the climatological station. For the seasonal totals along this coast, 1.4 comes very close.

suggest that any basic discrepancy in reporting between the Posts at Fort George and Eastmain and the respective modern climatological stations would be minimal. But, in the case of the HBC Posts at Great Whale and Little Whale River, allowance should be made for the modern record at Great Whale.

Besides the daily occurrence of precipitation, Journal remarks frequently indicate the intensity or duration of the fall, while others may sum up the wetness (or dryness) of a period or season. The nature of the months is also suggested by the number of "fine" days recorded. Proxy weather records relating to wetness provide further indication of intensity or duration of precipitation or periods of drought: for example, with respect to crop progress or damage, haymaking, forest fires, penetration of buildings, flooding, prevention of construction and other outdoor work, delays in hauling, travelling. While many of the historical reporters were vigilant in their observation and diligent in their recording of precipitation, this wealth of supplementary and proxy data provides both important supporting evidence and an aid in assessing those periods when counts appear to be less complete.

FORM OF THE INDEX AND METHOD

The index consists of a 5-point scale, ranging from very dry (-2) to very wet (+2). For each Post, the class limits were based on the respective monthly and seasonal frequency distributions of the number of days with measurable precipitation at Great Whale, Fort George and Eastmain. Indices were assessed for each month, and for the season as a whole.

Following Pfister (1980), the upper and lower quartiles were chosen as the limits between wet and dry months or seasons. In addition, the upper and lower octiles define the very wet and very dry classes. Taking as an example the number of days with precipitation for the May-to-October season at Great Whale, this can be summarized as follows:

25%		50%		25%		% of cases.
12.5%	12.5%			12.5%	12.5%	
VD -2	D -1	0		W +1	VW +2	classes and weighting.
63	70	79	Median 96 100	110	125	GW, 1926-76 No. of days.

To gain a measure of the bimonthly wetness for each year, the weighting factors for the two months in question were simply added algebraically. The scale for the bimonthly index thus ranges from -4 to +4, with a value of 2 implying a wet (dry) period, and 3 or 4 very wet (very dry). In evaluating the index for the season, the addition of the monthly values offered a useful cross-check, especially in borderline cases. This was also a help in obtaining a single index for a month or season with more than one Post reporting.

With respect to procedure, the first step was to list the historical precipitation counts by month and for the season. An adjustment was then made at all Posts, to account for any omission of night-hour rainfall, and at Great Whale and Little Whale River to account for the greater vigilance in snowfall reporting at the Great Whale weather station. These adjustment factors are described in Table 6. The adjusted counts were then used to obtain the index.

The second step consisted in checking the monthly index against other weather information: whether precipitation was heavy or light, in showers or continuous through the day, against the number of fine days, wind direction, and direct remarks concerning drought or wetness. Modern guidelines were provided by tabulations of monthly means and extremes of total precipitation, and Treidl's (1979, 1981) tabulations for Great Whale of percentage frequencies of weekly precipitation amounts, conditional probabilities for dry and wet days, percentage frequencies of periods of consecutive dry days, and support data for haying.

A final check of the monthly index involved the various kinds of proxy information listed above. The occurrence of forest fires lends credence to a very dry index. Haymaking and the progress of the crops through the season were particularly valuable. The water requirements of the different crops are included in Appendix A, Tables 2a-e. The spring snow melt, the spacing of the rainy days, the intensity of the fall and the drying power of the intervening days were born in mind. The possibility that the gardens may have been watered to some extent was there, but only once in the century was this mentioned as occurring.

The sum of the evidence was brought to bear on the seasonal index. Dry and wet periods within the season often balance out over the entire period. For both the monthly and seasonal indices these checks were most helpful in borderline cases.

TABLE 6. Wetness index. Table of adjustments.

A. RAINFALL. To account for those days when rain fell only at night and may have been unreported. In summer, the working day began ~ 6 am.

Based on hourly observations at Great Whale, 1965, 1968, 1971, 1972, 1973, 1975. the percentage of days per month with rain only between 10pm and 5am averages:

MAY	JUNE	JULY	AUG.	SEPT.	OCT.	SEASON
15%	20%	19%	16%	14%	24%	18%

Adjustment to all the historical data: an addition of 18% of the average monthly number of days with measurable rainfall at Great Whale and Fort George (1941-1970) and Eastmain (1960-1972).

POST	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	SEASON
LW/GW	+1	+2	+3	+3	+2	+3	+14
FG	+1	+1	+2	+2	+2	+2	+10
EM	+1	+2	+3	+2	+2	+3	+13

B. SNOWFALL. To account for discrepancy in modern reporting of the number of days with snowfall between 24-hourly observing stations and climatological stations.

Based on concurrent daily observations at 2 sites at Great Whale 1957/1958, when the 24-hourly station recorded about 1·4 times the number of days reported by the climatological station.

To adjust the historical data at Great Whale and Little Whale River, the actual number of daily snowfall counts for the month or season was multiplied by 1·4. The following table was drawn up for convenience.

ACTUAL SNOWFALL COUNTS	1	2-3	4-6	7-8	9-11	12-13	14-16	17-18	19-21	22-23
ADJUSTMENT FOR LW AND GW	0	+1	+2	+3	+4	+5	+6	+7	+8	+9

Days with sleet and "hail" (ice or snow pellets) have not been included.

CONFIDENCE LIMITS

With the historical reporting of days with precipitation, the bias is towards dryness. However, the amount of supplementary weather and proxy information has provided a wide variety of evidence for cross-checking. Where the reporting was regular, few modifications appeared necessary to the index as defined by the adjusted counts; where precipitation information was irregular, this support material allowed an estimate to be made. Special attention was paid to dry and very dry periods. In the light of the frequency distributions of the seasonal indices (Figure 6 and Table 7), which show the central class consistently at about 50 per cent, and a sense of continuity in the shift in the extremes, I believe that the seasonal (and monthly) wetness series offer a good approximation for direct comparison with the modern values of the index. The most reliable indices are those for 1815 to 1820.

Within the series, the degree of confidence varies according to the amount and kinds of information available for any one season, the vigilance of the observer and the number of Posts reporting. The ranking of the years is similar to that described above for the thermal series. Again, coverage is excellent for 1815 and 1820 and least for 1800-1805, 1810-1814 and 1824-1827. Although a monthly resolution was not always possible in the latter periods, the total information from May to October permits a seasonal estimate. The years 1845 to 1856 lack regular precipitation reporting, but contain much relevant material on which to approximate the index. In Appendix C, the indices are classed according to reliability.

Mention should be made of the mid-summer months with respect to Great Whale and, to a lesser extent, Little Whale River. At Fort George and Eastmain, the success of the vegetable gardens and haymaking for winter feed for the animals was important and thus provided much useful information. At the two northerly Posts, there was less incentive for the reporting of mid-summer precipitation, unless for example it were sufficiently heavy to prevent outdoor activity, or to cause damage. During the latter part of the century, these two Posts have greater prominence, although usually either Fort George or Eastmain was also reporting, and the final index took all Posts into consideration. In general, this appeared to be a drier period all along the coast, but at times a north-south difference was present that could well have been linked with more northerly or southerly positions of the storm tracks. On these occasions a certain suppression of the wetness factor may have arisen from using more than one Post. Even if there is a degree of exaggeration in the dryness of some mid-summers towards the end of the century (cf. Figure 7b), that they were drier is, I believe, real.

In the absence of other evidence, the degree of confidence increases directly with the number of Journal days with precipitation, so on these grounds, the "wet" indices have an edge over the "dry".

THE WETNESS SERIES, 1800-1900

The seasonal series of wetness indices for the nineteenth century is plotted in Figure 5. Figure 6 and Tables 7 and 8 show the frequencies and sums for different periods within the century. For comparison, the respective modern series have been included. The bimonthly sums are illustrated in Figures 7a-c. All the series are listed in Appendix C, together with the monthly indices.

May to October

In general the first half of the century was wetter and the second half drier than average (Figure 5,6). By far the wettest decade was 1811-1820, but the wet period extended to 1843. The extremely wet seasons were 1816, 1817, 1820, 1842, 1843. Drier seasons occurred in the earlier years of the century, and from 1850 with increasing frequency (Figure 6, Tables 7 and 8). The driest decades of the century were 1871-1880 and 1891-1900, the driest years, 1807, 1809, 1878.

Figure 6 illustrates the shifts in the frequencies of dry and wet seasons from 1800-1850 through to the present. It would appear that the change to drier conditions which began about 1850 continued into the early 1930's along this coast, culminating in the decade 1919 to 1928, which (according to the existing record) is almost without positive monthly indices. (Appendix C, Table C-2.) Wet seasons returned in the 1930's, and the distribution for 1934-1983 is very similar to that for the first half of the nineteenth century. This is also seen in Tables 7 and 8.

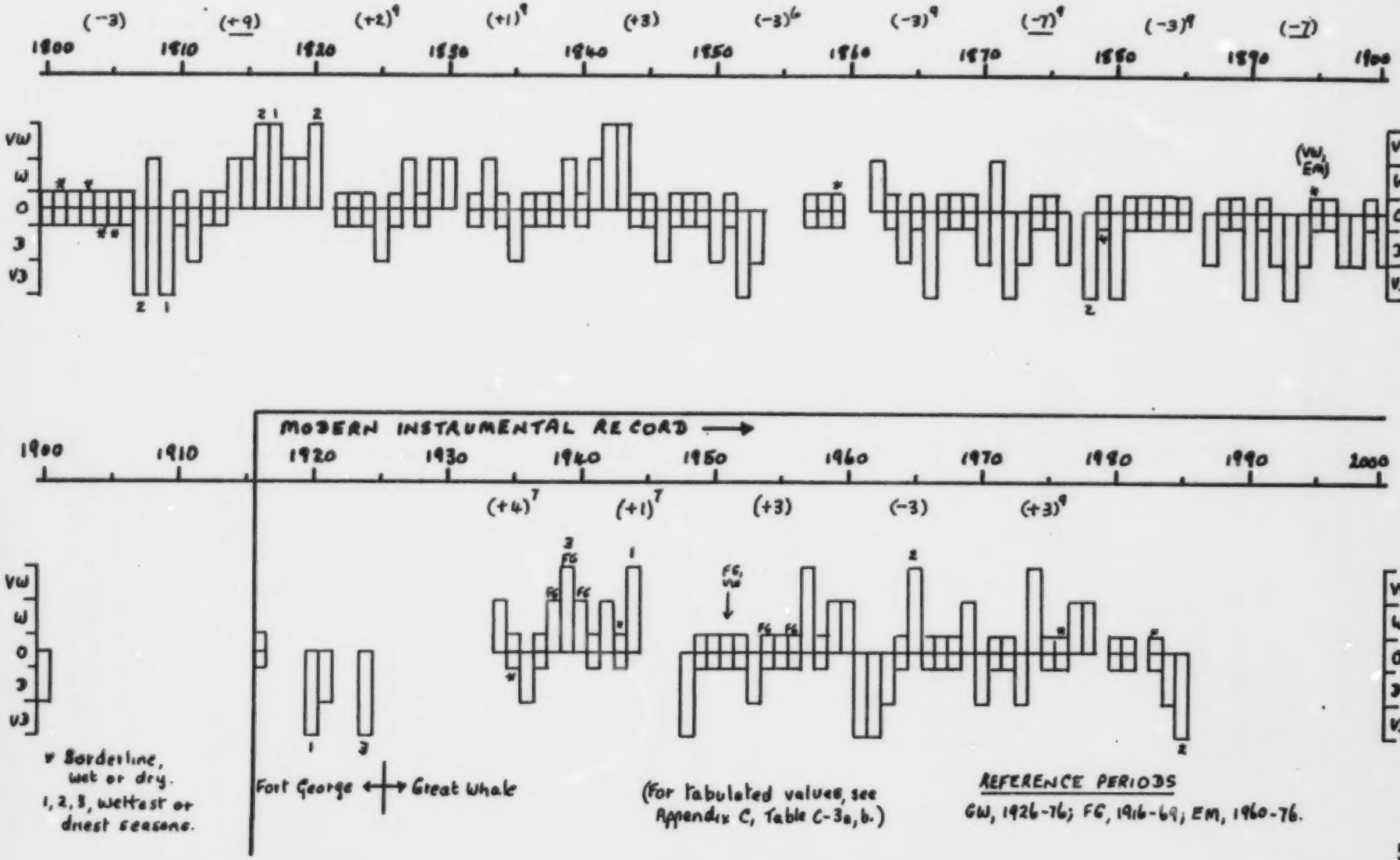
By summing the monthly indices for the season, an idea of the ranking of the wet and dry seasons is obtained. The wettest modern May-to-October, 1944, is similar to 1816 and 1820; only 1817 is marginally wetter. The driest modern season, 1920, is only matched (and slightly surpassed) by 1809.

May/June, July/August, September/October

Looking at the bimonthly breakdown for the nineteenth century (Figures 7a-c, Table 8), the seasonal pattern is reflected in the spring and mid-summer series, with extremely wet springs in the first

FIGURE 5. East coast Hudson/James Bay. Wetness indices, May to October, 1800 to 1900.

( ) Decadal sums of the index; superscript, no. of years. Index from +2, Very Wet to -2, Very Dry.



* Borderline, wet or dry.

1, 2, 3, wettest or driest seasons.

(For tabulated values, see Appendix C, Table C-3a, b.)

REFERENCE PERIODS

GW, 1926-76; FG, 1916-69; EM, 1960-76.

FIGURE 6. Seasonal wetness indices: relative frequencies 1800-1850, 1851-1900, 1916-1933, 1934-1988, and 1800-1900.

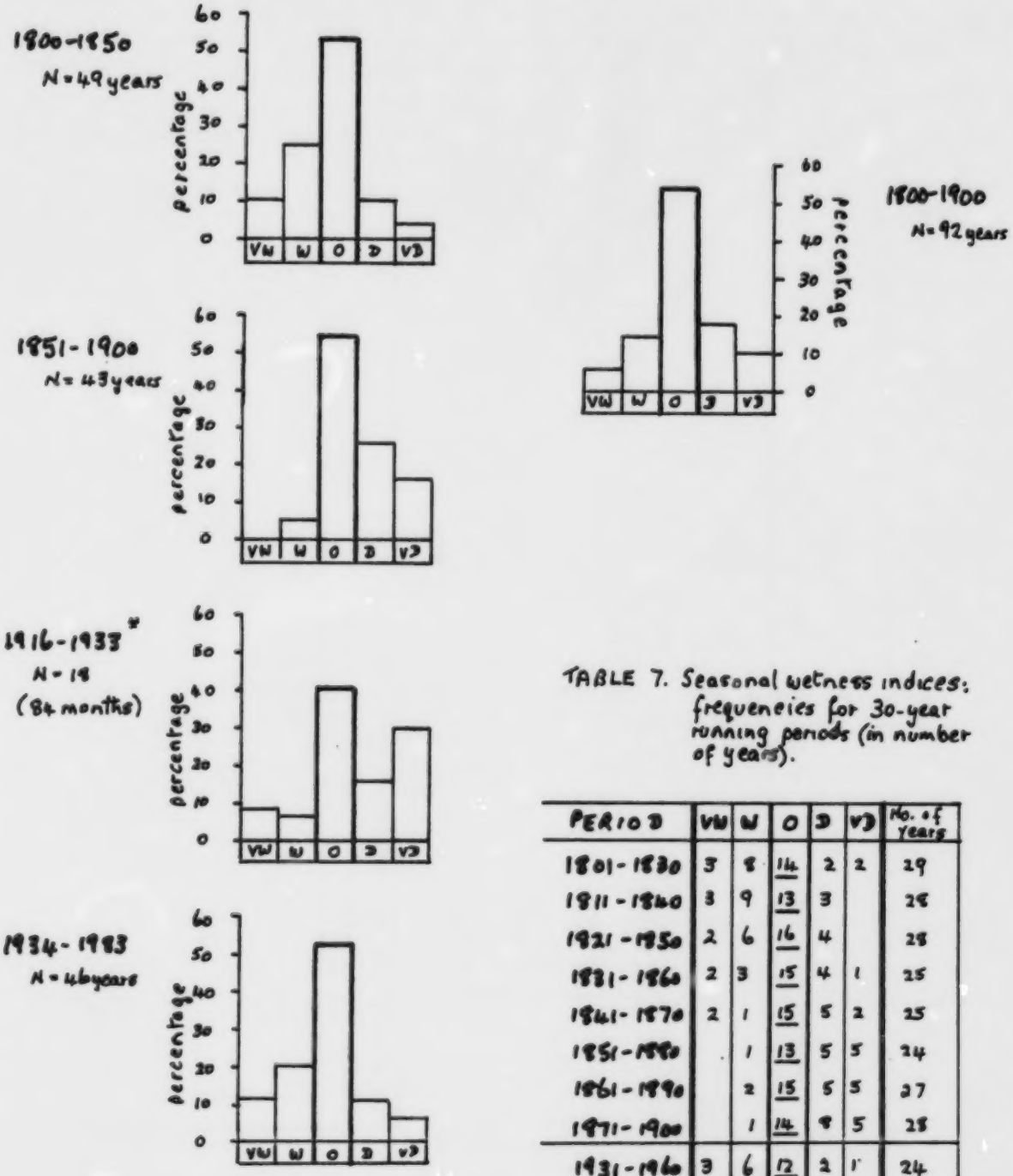


TABLE 7. Seasonal wetness indices: frequencies for 30-year running periods (in number of years).

PERIOD	VW	W	O	D	VD	No. of years
1801-1830	3	8	14	2	2	29
1811-1840	3	9	13	3		28
1821-1850	2	6	16	4		28
1831-1860	2	3	15	4	1	25
1841-1870	2	1	15	5	2	25
1851-1880		1	13	5	5	24
1861-1890		2	15	5	5	27
1871-1900		1	14	8	5	28
1931-1960	3	6	12	2	1	24
1941-1970	3	4	14	3	3	27
1951-1980	3	5	15	4	2	29

*Based on the frequency of the monthly values over the period. (cf. Appendix C, Table C-2.)

TABLE 8. Wetness indices: decadal sums, 1801 – 1900, 1921 – 1980.

DECADE	M/J	J/A	S/O	Season
1801-1810				-3
1811-1820	+15[7]	+7[8]	+12[8]	+9
1821-1831	-1[6]	+4[7]	-3[6]	+2[9]
1831-1840	+4[9]	+1[8]	+1[9]	+1[9]
1841-1850	+8	-1	0	+3
1851-1860	-3[6]		+3[6]	-3[6]
1861-1870	-5[9]	-4[9]	-5[9]	-3[9]
1871-1880	-2	-12[9]	-8[9]	-7[9]
1881-1890	+1	-11[9]	+1[9]	-3[9]
1891-1900	-5	-12	-5	-7

(Superscripts: Number of years.)

DECADE	M/J	J/A	S/O	Season
1921-1930		-9		
1931-1940	+1[8]	+3	+3[8]	+4[7]
1941-1950	+1[8]	+6[7]	+4[7]	+1[7]
1951-1960	+3[9]	-2	+4	+3
1961-1970	+3	-7	-3	-3
1971-1980	0	+9	+6[9]	+3

N.B. The seasonal value is the simple summation of the seasonal indices for the period.

The bimonthly value is the combined summation of the 2 monthly indices for the period.

For the modern reference base, for Great Whale, Fort George and Eastmain – the number of days with measured precipitation and total precipitation – see Appendix C, Table C-2.

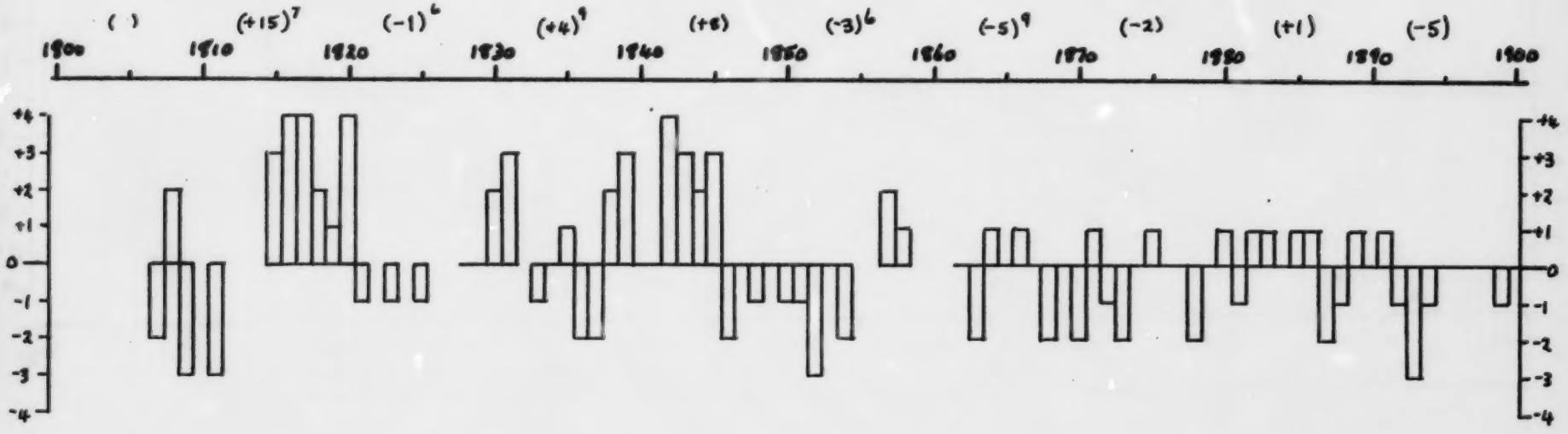
half of the century, and dry/very dry mid-summers in the last 50 years. The autumn pattern is less clear through the century as a whole, and extremely variable in the latter half. Perhaps, for the historical period, the most striking feature is the extreme wetness throughout the season from 1814 to 1820, and for the modern period the extreme drought throughout the season in the 1920's.

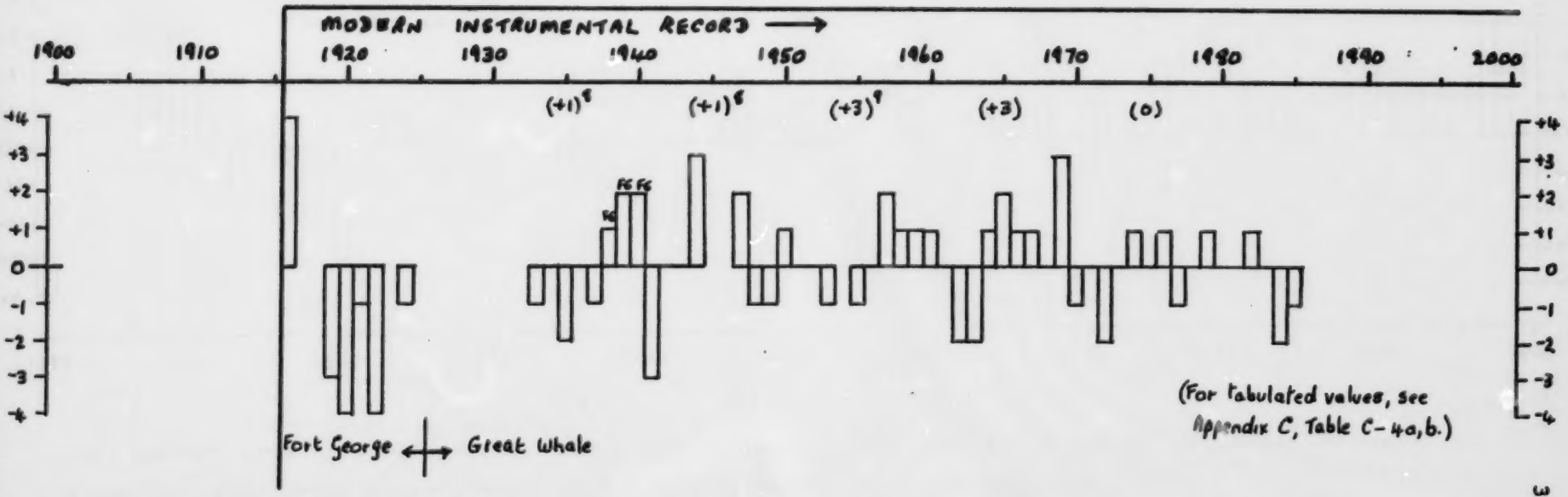
The only other wetness series presently available for comparison, within the general area, is that of Allsopp (1977), for the Red River Basin of southern Manitoba. From 1800 until meteorological observations were made at Winnipeg in 1872, Journals, diaries and proxy data were used to obtain a seasonal measure of agricultural weather (dry, average, wet). The crop season was typed according to which of a series of parameters (for example, pre-growing season soil moisture, spring planting weather, growing season precipitation or heat stress, or harvest weather) most affected the crops, so the index may not always be directly comparable with that used here.

The resulting series for the Red River Valley points to a distinctly out-of-phase relationship between the two regions. In southern Manitoba the first half of the nineteenth century had a very high frequency (51%) of dry growing seasons, while in the latter half as many as 40 percent were wetter than average (cf. Figure 6). Between 1800 and 1850, there were two sustained runs of drought in the Valley, from 1816 and 1819, and 1837 to 1850. These coincided with wetter conditions on the Bay, with the timing quite precise in the former case (Figure 5); the only run of wet growing seasons in Manitoba at this time was from 1831 to 1836. From 1851 to 1900, the two wettest growing periods were 1851-1861 and 1872-1882, again out of phase with the Bay, particularly in the latter case which was one of the driest decades of the century. Following the drought of 1883, 1884, the end of the century in the Valley was close to average. Comparing the two regions for this century (cf. Figures 5 and 6), drought characterized both from 1916 to 1933; this drought was prolonged in Manitoba until 1955, in contrast to the markedly wet period on the Bay from 1934 to 1944. A wetter regime was finally established in the Red River Valley after 1955, and continued until the end of the series in 1975. That the nineteenth century relationship between wet and dry periods for the two regions was largely out of phase seems consistent with that for the modern instrumental period and with the size and patterns of behaviour of the weather systems.

FIGURE 7a. East coast Hudson / James Bay. Wetness indices, May / June, 1800 to 1900.

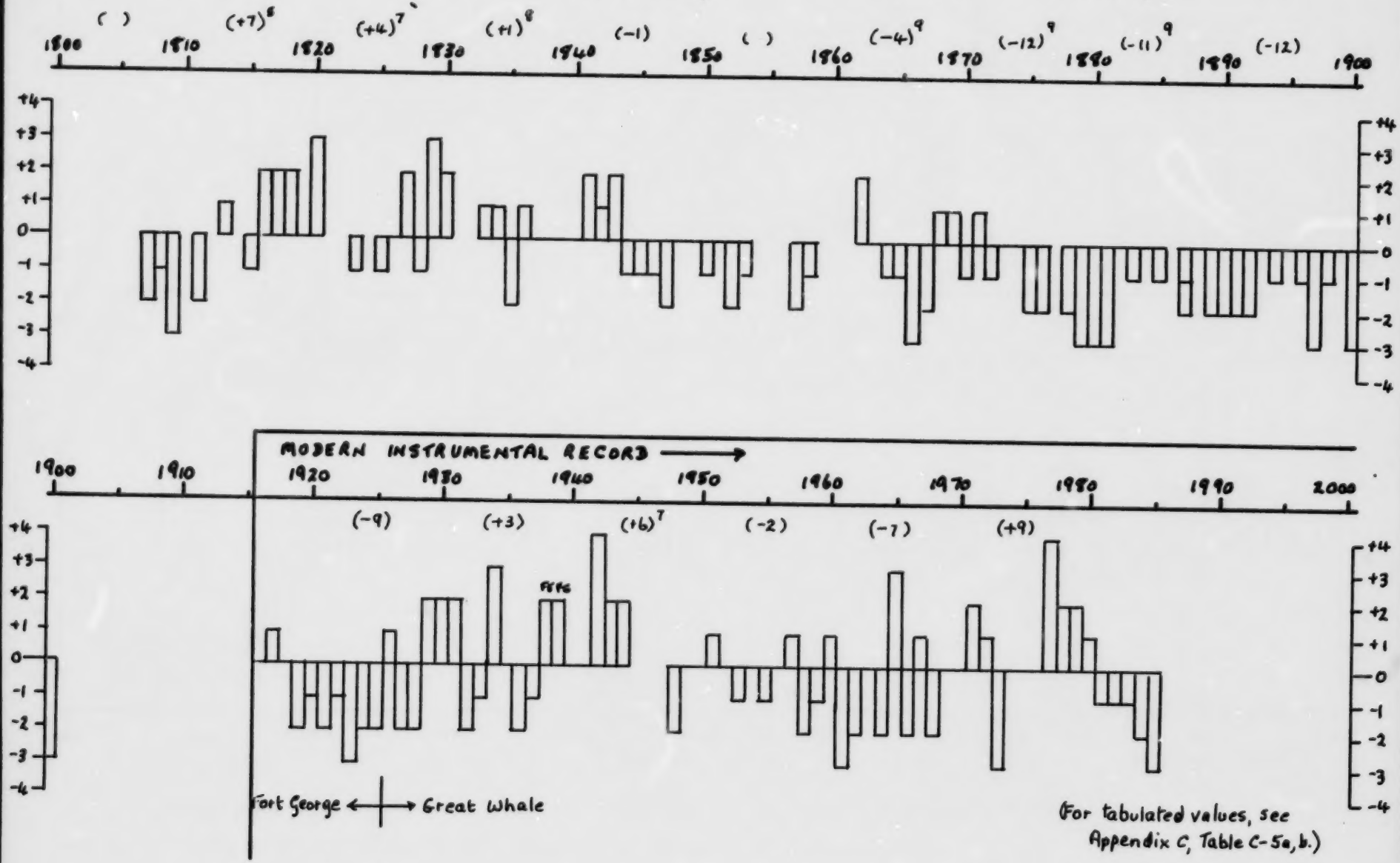
( ) Decadal sums of monthly indices; superscript, no. of years. Index from +4, Very Wet to −4, Very Dry.





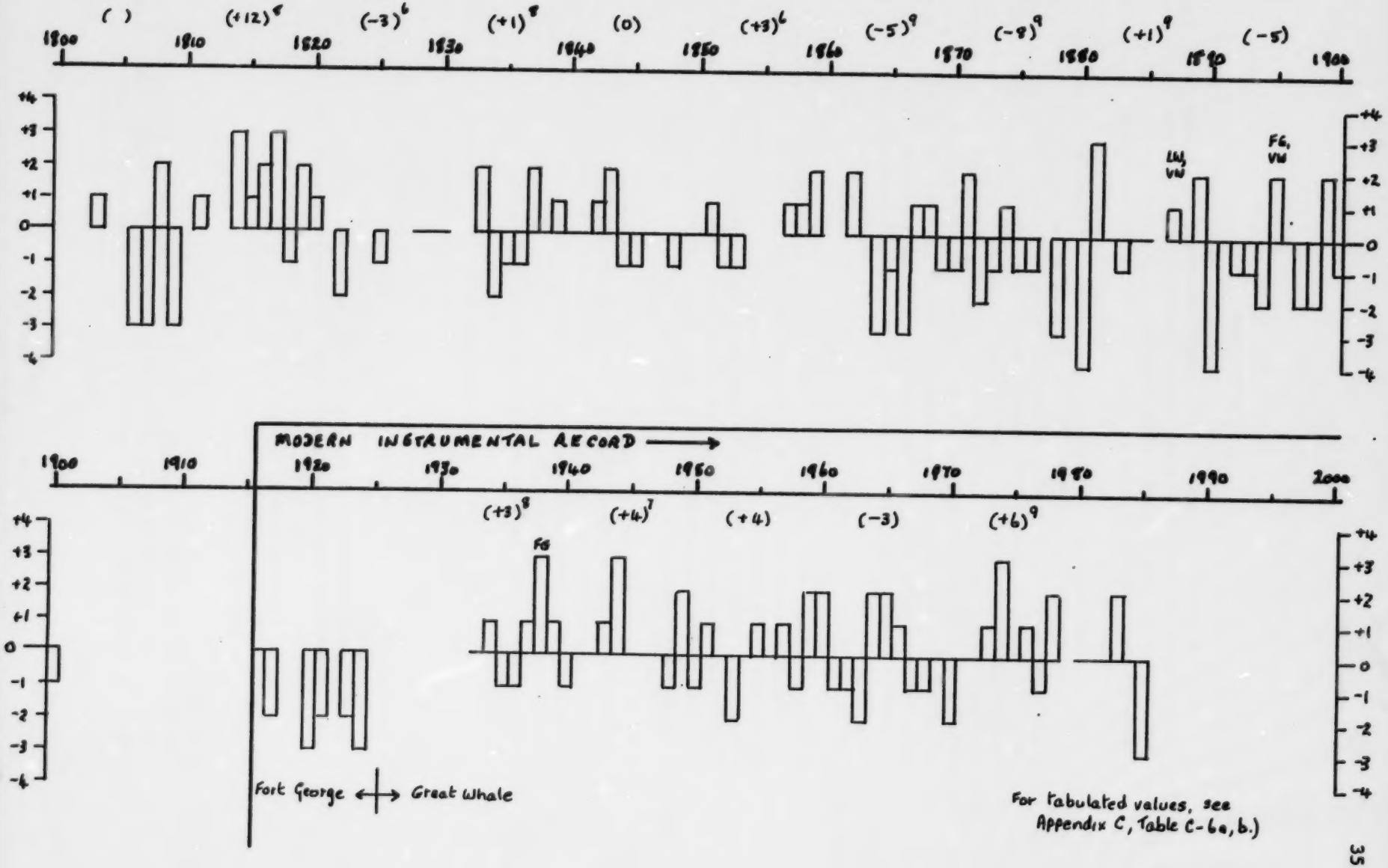
(For tabulated values, see Appendix C, Table C-4a,b.)

FIGURE 7b. East coast Hudson/James Bay. Wetness indices, July/August, 1800-1900.
( )Decadal sums of monthly indices; superscript, no. of years. Index from +4, Very Wet to -4, Very Dry.



(For tabulated values, see Appendix C, Table C-5a, b.)

FIGURE 7c. East coast Hudson/James Bay. Wetness indices, September/October, 1800 to 1900.
( ) Decadal sums of monthly indices; superscript, no. of years. Index from +4, Very Wet to -4, Very Dry.



For tabulated values, see Appendix C, Table C-6a, b.)

CONCLUSIONS

For the east coast of Hudson/James Bay, the results of this study indicate an extraordinarily rapid fall in May-to-October temperature in the second decade of the nineteenth century to values below those recorded in the present century. This was accompanied by precipitation well in excess of the average, including a much higher proportion of snowfall than that known today. Following this, seasonal temperatures well-below the 1941-1970 normal remained characteristic until the early 1870's when a series of warm to near-average seasons heralded a quite remarkable return to the energy level of the benign first decade of the century and to that of today. A clear upward trend in temperature can be seen from the decade 1811-1820 to 1871-1880. Until mid-century, seasons were frequently wet, but increasing dryness followed and the warmth and mildness of the last 30 years were often accompanied by drought. This pattern of climatic change for the May-to-October season through the nineteenth century has no analogue in the present century.

The climate from 1814 to 1821 has been described in detail in Part II. The years 1816, 1817 provide the closest analogue we have as yet in this region with respect to the formation of a permanent snowcover -- that is, to incipient glaciation. In Part II, this was discussed in detail, including the question of possible causes of the rapid climatic deterioration, which was not confined to this region. The discussion was developed further in Wilson, 1985b, and will only be touched upon here.

Two coincidental and now much-studied events are the massive volcanic eruption of Mount Tambora in April 1815 and the very low total sunspot count for the cycles at this time. A third event, now increasingly well-documented, is the extraordinary outflow of arctic sea ice in 1816 and 1817, reaching far to the south, in association with well-developed meridional atmospheric circulation.

(i) The climatic deterioration appeared to have begun before the advent of Tambora. Perhaps the explosion served to overload an atmosphere already charged with volcanic debris from eruptions in the previous years[5] (cf. Lamb, 1970). The deterioration at the time of the eruption of Mount Coseguina in 1835 may be a similar case in point. The general level of volcanic matter in the atmosphere through much of the nineteenth century seems to have been greater than for the reference period, and particularly so in the earlier decades.

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[5] I thank Bruce Findlay (Canadian Climate Centre) for this suggestion, and for a helpful discussion related to these concluding remarks.

(ii) With respect to the decline in solar activity at this time, it is interesting to note the dearth of mention of the aurora in this region during this century. At Great Whale during the 1970's, quite spectacular aurorae were a very frequent occurrence during this season; they were recorded there by the National Research Council. Although many of the HBC "observers" were interested in natural phenomena, the only mentions of the aurora at these four Posts were in October 1878 (on the 20th and 22nd, very far south), March/April 1879 and March/April 1880.

(iii) The question of the break-up in 1815/1816 of arctic pack ice that had been inpenetrable "for centuries" is raised by a letter in the Minutes of Council of the Royal Society, dated November 20, 1817 (cf. Wilson, 1985b, p. 188). This would fit in well with the evidence of the heavy outflow of ice in 1816 and 1817 (and low sea surface temperatures), but begs the question as to how this might have occurred at this time. Would the amelioration around the turn of the eighteenth century have been enough? Or is some catastrophic force required to bring this about? Could the necessary kinetic and heat energy have been released by submarine crustal activity at this time of general instability? (Wilson and MacFarlane, 1986.) There can be no doubt that heavy and late ice on the east coast of the Bay in 1816 and 1817 together with persistant northerly and westerly winds played a large part in the suppression of air temperature for those seasons.

The slow upward trend of temperature from 1817 to the 1870's, the re-establishment in the 1870's of the temperature level of the first decade of the century, and the subsequent flattening of the curve are not easily explained solely in terms of an increase in atmospheric CO_2 through man's activity (the burning of fossil fuels and the removal of vegetation).

In retrospect. The historical data was approached as far as possible in physical terms, from the standpoint of small-scale climatology, the approach of Landsberg (1967) and Geiger (1965). In this, the experience of field work at Great Whale[6] -- field measurement of a number of weather elements and of surface energy exchanges, as

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[6] I am grateful both to the Centre d'Etudes Nordiques, Université Laval, Québec, and to the Atmospheric Environment Service for financing this work.

well as the keeping of personal weather Journals, over a number of summer seasons -- has played an integral part. The historical approach to the material was the traditional one, in which the researcher does the abstracting, so as not to lose the vital information offered by the context and subtext. With this in mind, the weather and proxy data were also abstracted in context. Watching the passage of the weather day-by-day, month-by-month over the century, I was struck by the extraordinary balance of extremes within the season in so many cases.

In prospect. A large body of work is accumulating for the study of recent climatic change in the Hudson/James Bay region. Besides the temperature reconstructions of Guiot (1986) and Jacoby et al., and the tree-ring series for Cri Lake (Parker et al., 1981), there are time series for temperature and other weather and weather-related information for the west side of the Bay (Ball and Kingsley, 1984; Catchpole and Ball, 1981), series showing the summer ice severity for Hudson Strait (Catchpole and Faurer, 1983) and in eastern Hudson Bay[7] (Catchpole and Halpin, in press), tree-ring series generated by Payette et al. (1985) to the north of Great whale, and those of Cropper and Fritz (1981) just outside the area at Fort Chimo. I hope now to return to the data used in this study and to summarize briefly the main climatic characteristics by decade. I should also like to look at the results presented here in relation to these other series mentioned above and in the context of events outside the region.

As Gordon Manley believed, the Hudson/James Bay region per se may prove to be of particular interest in the study of climatic change in Canada as a whole.

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[7] My thanks to Alan Catchpole for kindly sending me a pre-publication copy.

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Abbreviation: AES, Atmospheric Environment Service, Canada.

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APPENDIX A

THERMAL INDEX - SUMMER GUIDELINES

SUMMER GUIDELINES

PROXY INFORMATION

The gardens at Fort George (53.50N) and Eastmain (52.15N) are the principal source of proxy weather data. Their approximate sites through the century are known (cf. Part I). At Fort George, they were on sandy soils, originally lichen-covered, and well-manured. At Eastmain, the soil was probably closer to a silty loam, again well-manured. Some of the gardens probably had favourable microclimates.

Cool season crops such as potatoes, cabbages, turnips, peas, carrots, radishes, parsnips, broccoli, onions, leeks, rhubarb, barley and oats were all planted at various times. The staple crop was the potato, and turnips and cabbages were also regularly sown. Dates of manuring, first digging, planting and sowing are usually given, and of the digging up of the potatoes and turnips, with a note as to their quality and quantity. Other mentions include emergence, weeding, hoeing and more rarely transplanting. When frosts "blighted" or destroyed the plants, this was noteworthy, as were those occasions when "the grub" attacked or cut down the potatoes. Drought was very rarely mentioned specifically with respect to the crops; they may have been watered, but this was only mentioned once in the century. Perhaps any waste water was regularly applied, as was often the case in England, earlier this century. Unfortunately the fate of crops which would have matured earlier in the season (such as peas) was rarely mentioned, although pea sticks were cut some years.

POINTERS

Harris et al. (1972) suggest as limits for successful crops in northwest Canada (north of 55N), at least an 80-day period free from killing frost (28F, 2.2C, in screen), a growing season of 110 days with mean daily temperature above 42F (5.6C) and an accumulation of 1000 growing degree-days, base 42F. A threshold of about 5C is accepted for growth for most cool-season crops. Fort George and Eastmain have rather shorter day-length.

Considering the time available for growth, Bunting (1975) divides temperate region crops into three groups, according to that part of the growing season in which the yield is produced: plants where the yield may be produced throughout much or all of the vegetative period, such as Irish potatoes, turnips, many other roots and tubers and wild grasses; where the yield is related to a greater or smaller fraction of the crop's life, for example, peas; and where the yield is produced in the latter phase of the life of an annual crop, as with the grain-filling time for barley and oats.

The lethal temperature limits, the limits for vegetative growth and the optimum temperatures for plant growth (the cardinal points) vary through the season and for different plants (cf. Treidl, 1978). In general, cool season crops do not tolerate prolonged periods with temperatures above 20C. A touch of frost at 0C may not be important, but at -2.2C can be killing at certain stages of growth. The differences between screen temperature, temperature near the surface and soil temperatures must be born in mind.

HEAT-UNIT APPROACH

This follows the method pioneered in Canada by Holmes and Robertson (1959) for assessing the relative progress of crops during a particular season. The heat unit is defined in terms of the degree-day above a growth threshold temperature for a particular crop: for cool season crops, 5C. This approach depends on knowing the dates of the planting and subsequent stages of the crop to harvest and the number of heat units (or growing degree-days) required to attain each stage. Then the rate of the degree-day accumulation during a particular season can be compared with the normal. Each cultivar is thus assumed to have a summation constant - a number of degree-days required for development from planting to maturity. Figures A-1a to 1c for Great Whale, Fort George and Eastmain show the normal degree-day accumulations base 5C, 10C, dates of last and first frosts, and the length of the growing seasons for the modern reference period, in the general format used by Agriculture Canada (Edey, 1977). Other probabilities for the cumulative degree-days, base 5C, were given in Part III A, Appendix E. Figures A-2 and 3 illustrate the weekly accumulation of degree-days, base 5C, and the freeze probabilities during the season.

Although lack of knowledge of the actual variety[1] of the vegetable and at times missing information concerning the stages of crops limited the detail which could be obtained by this method, it proved very useful as a general indicator of the distribution and amount of energy received during the season. For example, when a growing season was late in beginning in June, but first hoeing was carried out about the average time in mid- to late July, and the harvest was reasonable, this suggested a mean July temperature at least average and probably rather above.

AGROCLIMATIC CAPABILITY

A useful variant on the heat-unit approach is the idea of agroclimatic capability classes (Eley and Findlay, 1977), in which the crop potential of a location is delimited in terms of growing degree-

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[1] Dr. Stuart Edey of Agriculture Canada helpfully suggested that the variety of potato may have been the "Irish Cobbler". The only mention during the century was as late as 1893 at Fort George, when some of the potatoes were said to be "Beauty of Ebrow".

days, the frost-free period and a moisture index[2]. These class limits were used together with the 1941-1970 growing degree-day and frost data to assess the potential for Eastmain, Fort George and Great Whale (see Part II, 111-114). The latter were estimated to fall into classes 4,5 and 6, respectively -- primarily hardy, cool-loving vegetables and some forage (Table A-1). Of the crops planted, the onions and peas would probably be beyond the range of this coast today, while the frost-susceptible potatoes and carrots (generally limited to favourable micro-sites in Class 3) would only be expected to produce a satisfactory harvest in good years, especially at Fort George. With the emphasis given to potatoes, this crop thus provides an excellent indicator because of its marginality.

Table A-1 indicates the range of crop potential in terms of the probability of seasonal degree-day sums. Concerning the variability of the classes, Eley and Findlay note that "the middle classes of the classification have narrow ranges of climate specifications because it is in these ranges that the range of possible cultivation rapidly changes with climate. Where frontier locations have class 3 or 4 agroclimate on the average, and a considerable climatic variability, there will be great differences in agricultural success from year to year" (P. 85). Thus the type, quality and quantity of garden produce can be broadly interpreted in terms of the thermal limits of the class to which that season belongs. This approach proved very useful.

CARDINAL POINTS

The chief crop indicators were potatoes, turnips, cabbages, barley and oats. The limiting and optimum soil and air temperatures for these crops at various stages of growth are tabulated in Table A-2, together with other information on light, water and soil requirements and pests and diseases. Limits for other vegetables were obtained but rarely used. In the case of the wild grass used for haymaking, it was assumed that most grasses resume growth at 2 to 3C. The principal reference was Dubé (1981).

The relationship between air and soil temperatures through the season was studied in some detail (van Wijk, 1965; Geiger, 1965; Chang, 1968), and with particular reference to selected sites in Canada (Carder and Siemens, 1971; Harris et al., 1972, Ouellet, 1975; Aston, 1973). Monthly soil temperatures at 10 cm were then estimated for the garden sites at Fort George and Eastmain (Table A-3). The estimates were based on a series of air and soil temperatures measured at Great

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[2] For eastern Hudson/James Bay, the moisture deficit term was omitted.

Whale, near the time of the daily maximum, in June, August and September 1974 (Figure A-4), on the mean daily range of soil temperatures at Goose, Fort Chimo (sandy soils) and Ottawa (clay loam), and on the seasonal curves of mean daily air and soil temperature for these three stations in relation to those for air temperature at Great Whale, Fort George and Eastmain. The site at Great Whale was a sheltered, very gentle south-facing slope, from which the lichen cover had been removed to expose a sandy soil containing dark, organic matter. The timing of snowcover was born in mind. Soil temperatures become less extreme as the plant cover develops.

FIGURE A-1a. Temperature diagram for heat-unit approach.

GREAT WHALE 1961-1970. Cumulative degree-days, base 5C and 10C (Aston, 1977).
Average dates of transition through 0C, 5C, 10C, daily mean temperature.
Last and first average dates daily minimum temperature of 2.2C, 0C (Hemmerick and Kendall, 1972).

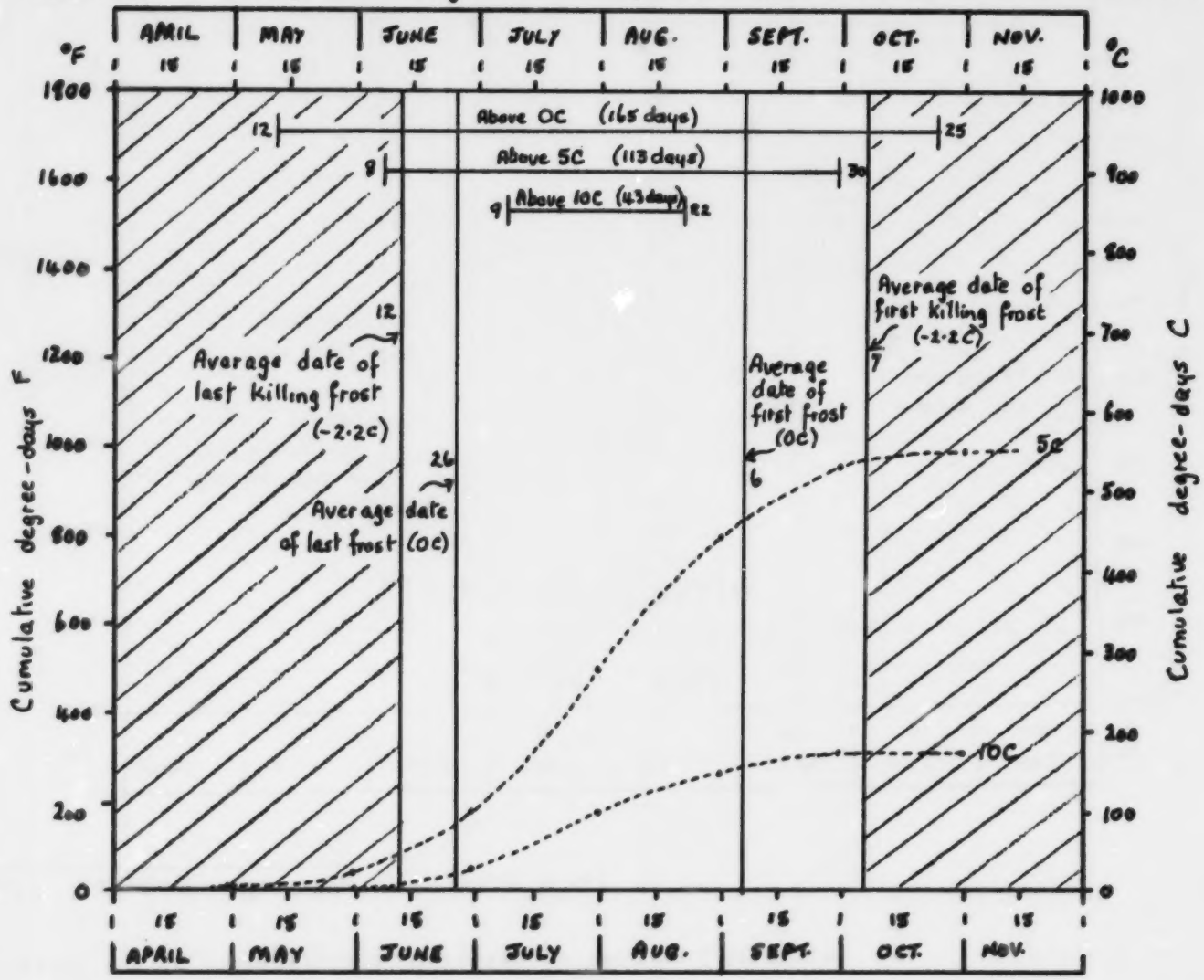


FIGURE A-1b. Temperature diagram for heat unit approach.

FORT GEORGE 1941-1970 (see Figure A-1a)

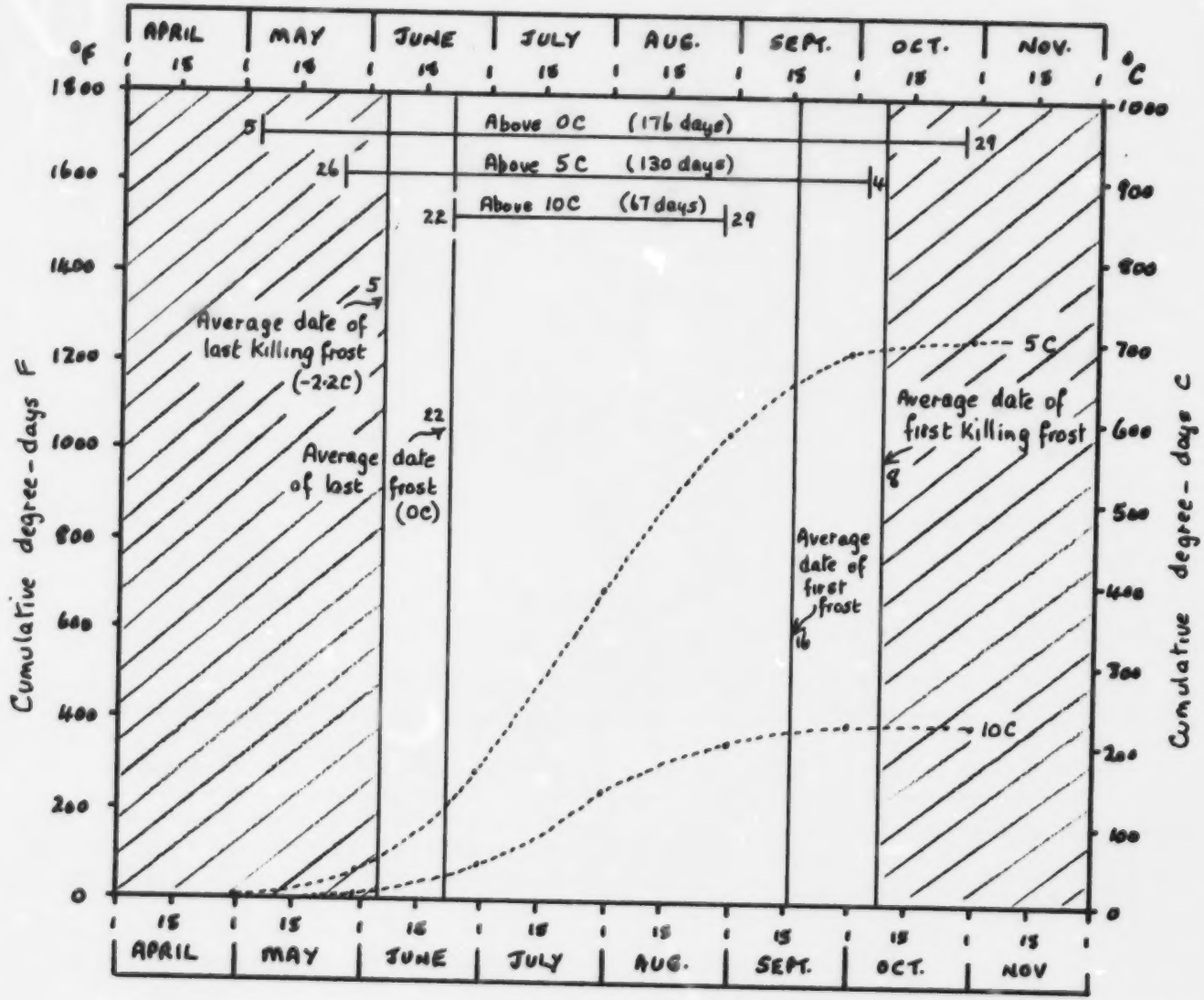


FIGURE A-1c. Temperature diagram for heat unit approach.

EASTMAIN. WITHIN 1960-1980 (See Figure A-1a.)

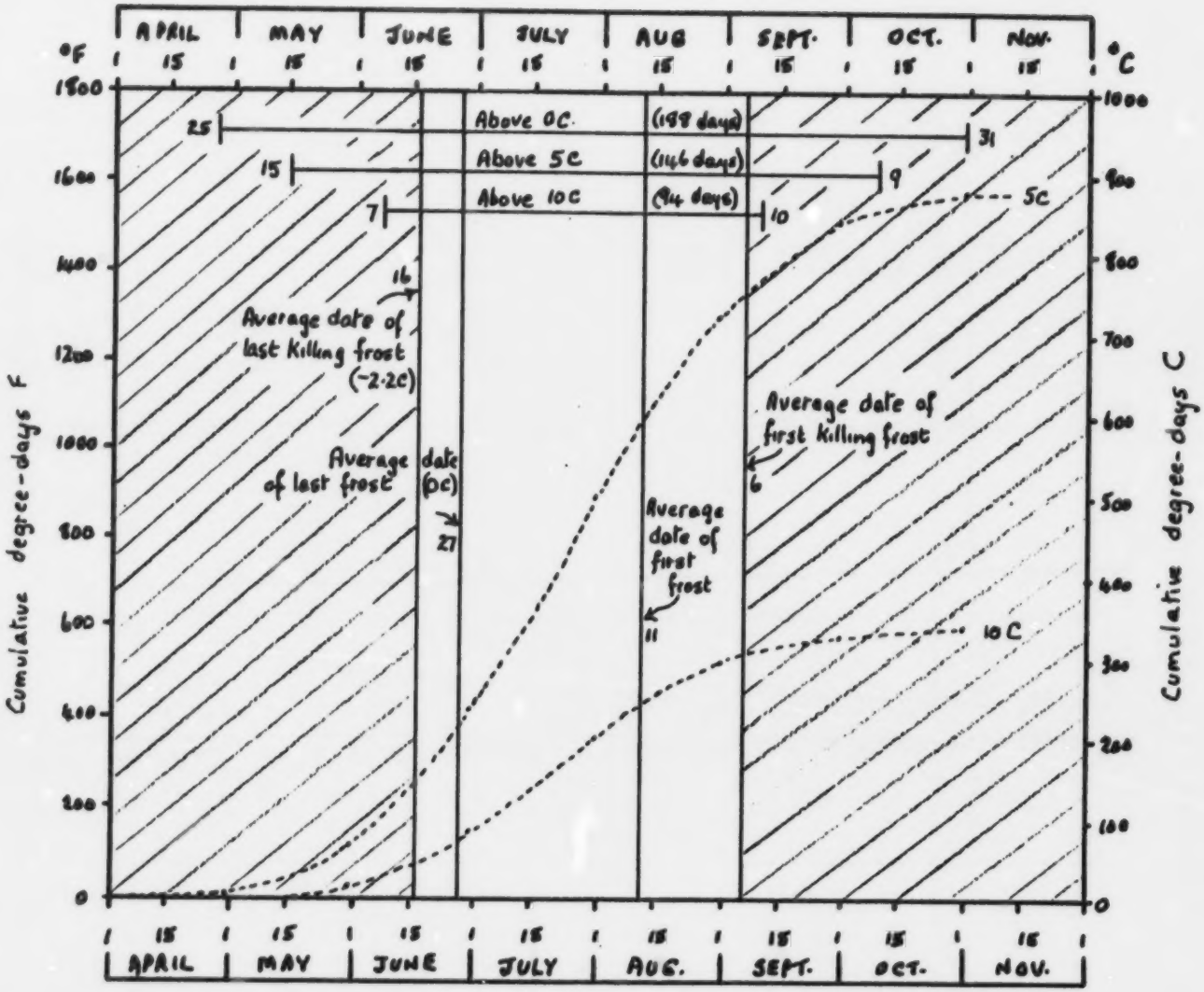


FIGURE A-2.

GREAT WHALE 1941-1970. Average weekly accumulations of degree-days (base 5C).
(Data from Treidl, 1979. Part I, Table 5.)

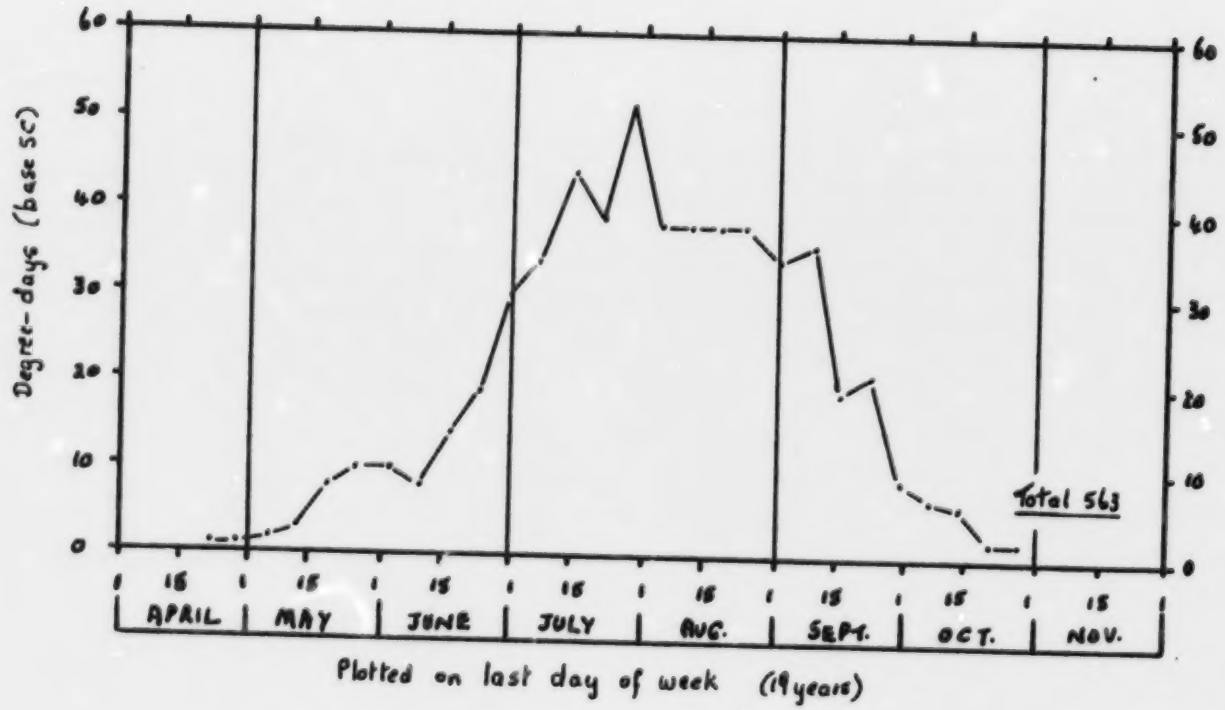
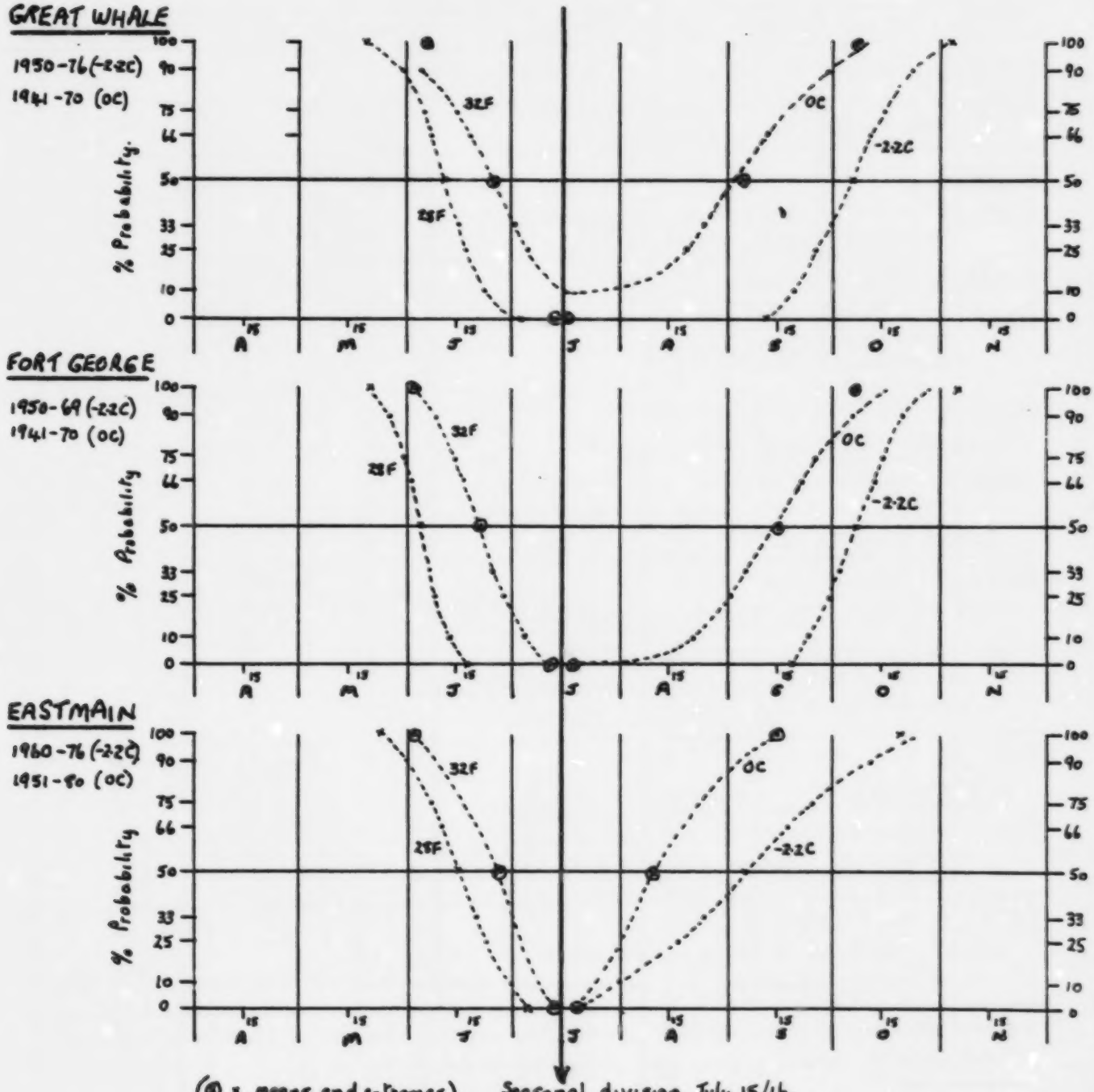


FIGURE A-3. Freeze probabilities for Great Whale, Fort George, Eastmain. Chances of last frost and of killing frost on or after any date in spring and on or before any date in fall. (cf. Thom and Shaw, 1958)



(⊕ =, means and extremes.) Seasonal division, July 15/16.

TABLE A-1. Phenological indicators: Agroclimatic capability, Eastmain, Fort George, Great Whale.

REFERENCE DATA. 1941-1970

GDD = Growing degree-days, base 5C (Aston, 1977). FF = Frost-free period in days, daily minimum temperature >0C (Hemmerick and Kendall, 1972). Plants are those mentioned in the HBC Post Journals.

THERMAL CLASS LIMITS (Eley and Findlay, 1977)	MODERN CLASS RANGE (GDD)
CLASS 1. GDD > 1145; FF > 90. **Crops:** As in CLASS 2, plus peas and seed onions where microclimate favourable	
CLASS 2. GDD 1000-1145; FF 75-90. **Crops:** As in CLASS 3, but including potatoes (although frost prone), carrots, lettuce.	← 20% (1968 FF 88)
CLASS 3. GDD 870-1000; FF 60-75. **Crops:** As in CLASS 4, with frost susceptible species such as potatoes and carrots where microclimate favourable.	← 2 s.d. (1969 FF 111)
CLASS 4. GDD 735-870; FF 50-60. **EASTMAIN.** GDD 876; FF 44 (12 to 88)[1]. **Crops:** Cabbages, turnips, radishes, parsnips, broccoli, rhubarb, barley, oats, forage. [N.B. MARGINALLY IN CLASS 3, BUT EFFECTIVE SEASON LIMITED BY FROST.]	← EM 50% ← 20% ← 2 s.d. (1969 GDD 751; FF 114; potatoes grown on fav. site.)
CLASS 5. GDD 615-735; FF 30-50. **FORT GEORGE.** GDD 701 (s.d. 110); FF 85 (19-111). **Crops:** Cabbages, radishes, broccoli, forage, with turnips, parsnips, rhubarb, barley, oats, where microclimate favourable. [N.B. NEAR UPPER LIMIT OF CLASS.]	← 80% ← FG 50% ← 20%
CLASS 6. GDD 500-615; FF > 30. **GREAT WHALE.** GDD 550 (s.d. 107); FF 71 (3-114). **Crops:** Cabbages, radishes, broccoli and some forage, all limited to sheltered sites and south-facing slopes	← 80% ← GW 50%
CLASS 7. GDD < 500. Usually confined to native pasture where microclimate favourable.	← 2 s.d. ← 80% (1965 GDD 282; FF 3.) ↓ 2 s.d.

N.B Wild varieties of fruits such as currants, strawberries, raspberries, blueberries, cranberries, gooseberries normally grow well along this coast today.

1. Eastmain: modern observing site on organic terrain, and more susceptible to radiation frosts in summer.

TABLE A-2a. CROP INDICATORS: POTATOES. Dubé, 1981; Treidl, 1978; Chang, 1968; Bunting, 1976; Bennett, 1982; Bourke, 1955; Grainger, 1967; Beirne, 1970; Zethner and Esbjerg, 1978; U.S. Department of Agriculture, 1941.

SOIL* AND AIR TEMPERATURES

STAGE	GERMINATION / EMERGENCE	VEGETABLE GROWTH	TUBER FORMATION	HARVEST
MAXIMUM	High soil and air temps. detrimental to normal plant development. Growth of leaves and tubers decreases		Tuber formation inhibited at 29C (84F) at 20-29C (68-84F)	
OPTIMUM	Rapid development of young sprouts at 23C* (74F). For healing seed cut just before planting, 16-21C* (61-70F). Rapid emergence at >12C* (54F)	Later growth best at 17, 19*C (62-64F)	Optimum tuber initiation and formation 15-22C (59-72F) ; night 10-14C (50-57F). Optimum to maintain max. growth rate; night, 10-18C (50-64F) ; day 20C (68F)	Best before soil temps. decrease to 7-10*C (45-50F)
	Growth rate and yield better where warm months not >19-20C (65-68F)			
MINIMUM	Germination and emergence slow at 7C* (45F).	Freezing injury ranges from nipping of leaves to killing back of plant to soil surface. (For some varieties, new stems form from buds below ground.)		If potatoes exposed for several weeks to temps. just above freezing, go sweet and unpalatable.
LETHAL LIMIT (Low resistance to frost)	Germination, -2, -3*C (28-26F) harmful	Leaves destroyed at -1C (30F). At flowering and fruiting stages -1C, -2C (30-28F) harmful. In North, late crop season often cut short by frosts killing vines prematurely.	Unseasonably hard freeze can injure tubers in soil before harvest and freezing a hazard through harvest, storage, transit.	Freezing point of potatoes averages -1.7C (29F); range -1.4 to -1.9C (29.5 to 28.6F)

NOTES (1) A growing season of 85-140 days, depending on the cultivar.
(2) Considered a less hardy cool-season crop.
(3) Night temperature the dominant factor — optimum about 12C (54F).
(4) In many instances, soil temperatures are more important than air temperatures to plant growth.
(5) High temperature injury, especially on sandy soils if soil unshaded by the vines.
(6) Yield produced through much or all of vegetative period. (Although potatoes sensitive to frost, planted early because increased yields from spring planting may more than offset effects of frost.)
(7) Importance of duration as well as intensity of frost.

LIGHT Remarkable response to day-length. Increase in aerial system as photoperiod increases. Short days induce tuberization. Yields higher under high light intensity.

(continued)

TABLE A-2a. CROP INDICATORS: POTATOES. (Continued.)

WATER	Plentiful and regular, especially from tuber formation to maturity. Minimum 250mm (10") during growing season. Ideally 20-30mm/week (0.8-1.2"/week). Shortage in July/August a limiting factor. Critical after formation of tubers. Where strong winds, shelter very effective.
SOIL	Deep fertile, well-drained soils with high organic matter levels and good water-holding capacity. Loams, sandy loams excellent because warm early in spring and ensure good growth. Sandy or organic soils too. Excessive moisture not tolerated.
PESTS and DISEASE	
RHIZOCTOMA.	Injury on growing points of young shoots underground, mainly at below 20C (68F), with damage at 12C (54F) most serious. Above 20C, rapid growth, and retardation of Rhizoctoma; shoots escape injury.
LATE BLIGHT	Atmospheric humidity affects foliage diseases. Minimum temperature not below 10C (50F), humidity 100% for 16hrs. Critical period 7 to 21 days before outbreak. (Others choose different criteria - i.e. dew, cloudiness, rainfall, relative humidity ≥75%, etc.) Damp cloudy conditions, with a min. temp. >10C (50F) = optimum. Province of Québec uses 7C (44F). Favoured by maritime climate.
POTATO ROOT EELWORM.	Hatching of worms requires a soil temp. of at least 7C (45F). If crop well advanced by then, safe.
CUT WORM	Precipitation is the factor. Years with many attacks, dry May/June or with dry hot or warm summers. Low cut-worm years, surplus of precip. May-July. High May precip. some assurance. Temps. lower in non cut-worm years, all months but May.

TABLE A-2b. CROP INDICATORS: TURNIPS and RUTABAGAS. Dubé, 1981; Treidl, 1978; Chang, 1969; U.S. Department of Agriculture, 1941.

SOIL* AND AIR TEMPERATURES

STAGE	GERMINATION/SEEDLINGS	VEGETATIVE PHASE
MAXIMUM	Germination rate and seedling development inhibited at 35C (95F).	Mean temps. >24C (75F) cause serious damage to leaves. Do not tolerate high temperatures. Insect pests especially severe during hot dry weather.
OPTIMUM	16-30C* (61-86F) (Treidl) Germination rate and seedling development optimal 15-18C (59-64F)	
MINIMUM	Germination rate and seedling development reduced at 5-6C* (41-43F)	Can tolerate slightly cold temperatures and foliage not affected at -1C (30F) (See note (1))
LETHAL LIMIT	-6, -7C (21-20F) (Chang)	

NOTES (1) Minimum, optimum and maximum growth temperatures rather similar to cabbage, but when immature plants will tolerate short periods of chilling at a mean of ~4.5C (40F) better than cabbage. When they reach marketable size, mild freezing weather less damaging than to cabbage.
(2) Growing season about 115 days for table varieties. Although critical temps. similar for turnips and rutabagas, latter require 4 months, turnips ~3 months.
(3) Cool humid climates - but wide temp. adaptation for growth. [Seed usually sown late to provide roots of desired size at fall harvest.]

LIGHT No limitation by photoperiod.

WATER Requires adequate, regular water supply, and tolerates dry periods if soil moisture available. Growth rate strongly reduced by excess water. Critical moisture-sensitive stage, when edible root increases rapidly, till harvest.

SOIL Grow well on fertile, well-drained soils with good organic matter and water-holding capacity. On sandy soils only if water available, but loams and clay loams more suitable. For sandy loam, need manure

TABLE A-2c. CROP INDICATORS: CABBAGES (BROCCOLI etc.). Dubé, 1981; Treidl, 1978; Chang, 1968; U.S. Department of Agriculture, 1941.

SOIL* AND AIR TEMPERATURES

STAGE	GERMINATION / EMERGENCE	(TRANSPLANTED) VEGETATIVE PHASE
MAXIMUM [seriously reduced]	30C* (86F) (Treidl)	>25C (77F) growth stops [With monthly mean >21C (70F), growth slow, abnormal and quality usually poor.]
OPTIMUM	(For good yields under cool temperate climates, started in greenhouses in early spring and transplanted to fields in May and June.)	15-20C (59-68F) Grows best at monthly means of 16-21C (60-70F). If it encounters cooler weather gradually, will approach head stage slowly at mean T. of 13 to 16C (55-60F) and stand safely for many days at a mean of ~10C (50F) to give long harvest of good quality.
MINIMUM	7C* (45F) (Treidl)	Growth minimal, 0C (32F). Young, well-hardened plants more cold resistant than older ones. Late varieties can still grow at 5C (41F) during fall. At head stage in fall or winter will stand frost, but freezing then is generally destructive.
LETHAL LIMIT	-5 to -7C (23-20F) (Chang)	-8 to -10C (18 to 14F) Damaged by sudden freezing when growing actively; at that period = "non-hardy." Winter varieties severely damaged below -10 to -12C (14-10F).

NOTES (1) Cultivars differ in frost tolerance as well as length of growing season required for maturation – a wide range.
(2) Length of growing season varies from 65-125 days, with varieties.
(3) Good growth under cool, humid climatic conditions.
(4) Is an annual for head production. As a crop, harvested in the vegetative phase.

LIGHT No limitation by photoperiod.

WATER Needs an adequate, regular supply. 870 - 1000 mm (34-39") during growing season. Critical moisture-sensitive stage, during head formation and enlargement.

SOIL Can grow on many soils if well-drained and fertile, with good water-holding capacity and adequate organic matter. Sandy soils ideal for early varieties; clay loams for late varieties. Organic soils too.

TABLE A-2d. CROP INDICATORS: BARLEY. Dubé, 1981; Treidl, 1979; Williams, 1974; Harris et al., 1972; U.S. Department of Agriculture, 1941.

SOIL* AND AIR TEMPERATURES

STAGE	GERMINATION EMERGENCE	VEGETATIVE GROWTH	HEADING AND GRAIN FILLING PERIOD
MAXIMUM [seriously reduced]	43C* (110F) (Treidl) [30C* (86F) (Treidl); inhibited above 35C* (95F) (Dubé).]	38C (100F) (Treidl) [30C (86F) (Treidl)]	Reproductive development inhibited at 37.38C (90-100F). Final yields seriously reduced at >30C (86F), and reduced at >25C (77F) (Treidl)] High temps., especially with hot winds, at heading and ripening may seriously interfere with development - excessive transpiration.
OPTIMUM	20C* (68F) (Treidl) 15-22C* (59-72F), according to variety (Dubé)	Growth optimum at 18-25C (65-68F) (Treidl) Growth optimum 10-16C (50-61F) during vegetative phase (Dubé)	18-20C (65-68F) (Treidl) During shooting to soft dough stages, 24-28C (75-82F) (Dubé)
MINIMUM	3-5C* (38-41F) (Treidl) 2-5C* (36-41F) (Dubé) Exposing seed in soil ≤7C* (45F) for more than 10 days reduces stands and yields. With soil temps. 3-6.5C* (38-43F), germination 95%; at 2-3C* (36-37F), 31%. (Harris et al.)	Growth minimum at 4C (39F) (Treidl); at 5C (41F) (Dubé)	5C (41F) (Treidl) During shooting to soft dough stages, 18C (65F) (Dubé) If temps. preceding harvest too low, grain ripens slowly, and if growing season short, risk of frost damage increased.
LETHAL LIMIT	Early spring freezes usually not very destructive, but if severe, damage may be extensive. -7 to -9C (19-20F) (Chang)	Young plants tolerate to -8C (18F) (Dubé); -9C (16F) (Treidl). Flowering stage, -1, -2C (28-30F) (Chang)	Fruiting stage, -2, -4C (28-25F) (Chang)

From shooting to shortly after heading = critical stage for any weather factor.

NOTES (1) Early spring varieties which grow further north require minimum 80-90 days from seeding to maturity, but precarious where frost-free period < 90 days. Normally limited to areas with frost-free period of 100 days or more.

(2) Under adequate conditions, 5-7 days required from seeding to emergence, 10-15 days from emergence to tillering (= putting forth new shoots from the original stalk). Barley grows particularly well where ripening season long and cool.

(continued)

TABLE A-2d. CROP INDICATORS: BARLEY. (Continued.)

NOTES	(continued) (3) Suited to areas with approximately 2100-3000 degree-days (base 42F), ~1167-1667 (base 5.6C), depending on varieties. (4) Barley most reliable of early-maturing spring cereals— matures more quickly than other cereals, and can be grown where relatively short growing season. Seeding must be done as early as possible, but late enough to reduce the risk of damage from late spring frosts and from planting into cold soil. (5) Barley = an agricultural frontier crop. EM and FG in the frontier zone, and FC near the outer limit. (Soil a.k. and climate on microsites.) Inner boundary = where barley would normally mature 30 days before the first fall freeze.
LIGHT	No limitation by photoperiod.
WATER	Requires 300-500 mm (12-20") annual rainfall (Canadian conditions.) Better growth with limited but regular rainfall. Growth poor in warm humid climates. Excessive water reduces growth rate. Development faster where precipitation low, thus reducing number of degree-days required to reach maturity. Adequate water supplies critical from shooting to shortly after heading.
SOIL	Deep, fertile, well-drained loam and clay-loam soils. (Cold, acid, clayey, sandy or organic soils not recommended.) Surface and sub-surface drainage needed for early seeding and vigorous growth.

TABLE A-2e. CROP INDICATORS: OATS. Dubé, 1981; Treidl, 1979; Chang, 1968; Harris et al., 1972.

SOIL* AND AIR TEMPERATURES

STAGE	GERMINATION/EMERGENCE	VEGETATIVE GROWTH	HEADING AND GRAIN-FILLING PERIOD
MAXIMUM [Seriously reduced]	43C* (110F) (Treidl) [30C* (86F) (Treidl); inhibited above 31C* (88F) (Dubé)]	40C (104F) (Treidl) [30C (86F) (Treidl)]	40C (104F) (Treidl) [Final yields seriously reduced at >30C (86F) (Treidl) Final yields reduced at >25 (77F) (Treidl)]
OPTIMUM	20-24C* (68-75F) (Treidl) 25-31C* (77-88F) (Dubé)	20-24C (68-75F) (Treidl)	20-24C (68-75F) (Treidl)
MINIMUM	5C* (41F) (Treidl) 0-5C* (32-41F) (Dubé) Exposing seed in soil ≤7C* (45F) for more than 10 days reduces stands and yields. With soil temps. 3-6C (38-44F), germination 72%; at 2-3C* (36-37F), germination 0% (Harris et al.)	5C (41F) (Treidl)	5C (41F) (Treidl)
LETHAL LIMIT	-8, -9C (16-18F) (Chang)	At flowering stage, -1, -2C (28-30F) (Chang)	At fruiting stage, -2, -4C (28-25F) (Chang)

NOTES (1) Growing season 80-120 days, varying with cultivar.
(2) Crop grown at latitudes up to 16C (61F) May isotherm, and 21C (70F) July. [N.B. May, FG: 2.8C (36.5F), Em: 4.1C (39.4F) July, FG: 12.4C (54.3F), Em: 13.2C (55.7F)]
(3) Accumulation of temperature over 4.4C (40F) is primary factor affecting maturity of oat varieties. For each variety the value is almost a constant.
(4) Suited to cool humid climates. [N.B. See "NOTES" for Barley, much of which applies here.]

LIGHT No limitation by photoperiod. Crop tolerates reduced light intensity (i.e. cloud too) better than many other small grains.

WATER A regular water supply, with a minimum 200-300mm (8-12") rainfall, May to Aug. [N.B. FG: 235mm (9.25"); Em: 275 mm (10.85").]
Susceptible to drought from early heading to grain maturity.
Although more water required than other small grains, excess moisture reduces growth.
Diseases common where more than 600mm (24") rain.

SOIL Suited to a wide range. Tolerant of medium fertility and imperfect drainage. Good sfc drainage essential for early planting on clay soils. They grow on sand, sandy loams, loams, clay loams, clays. Best yields on well-drained, fertile soils with adequate water-holding capacity.

TABLE A-3. Estimated 10-cm soil temperatures for garden sites at Fort George and Eastmain.

FORT GEORGE. A warmer soil than Em; site in forest clearing.

	A	M	J	J	A	S	O	N
pm °C	-2.7	4.2	13.3	16.8	15.3	11.3	4.9	-0.1
°F	27.2	39.6	55.9	62.3	59.5	52.3	40.8	31.9
am °C	-2.7	1.9	10.1	13.6	12.9	9.2	3.8	-0.3
°F	27.2	35.4	50.2	56.5	55.2	48.6	38.8	31.5
mean °C	-2.7	3.1	11.7	15.2	14.1	10.3	4.3	-0.2
°F	27.2	37.5	53.1	59.4	57.4	50.5	39.8	31.7

RANGE: June ~10-20°C; August ~10-23C; September ~5-14C.

EASTMAIN. If soil less warm than at Fort George, the pallisades at Eastmain may have afforded greater protection. The "turnip garden" on colder site, probably heavier soil, exposed, heavy drifts.

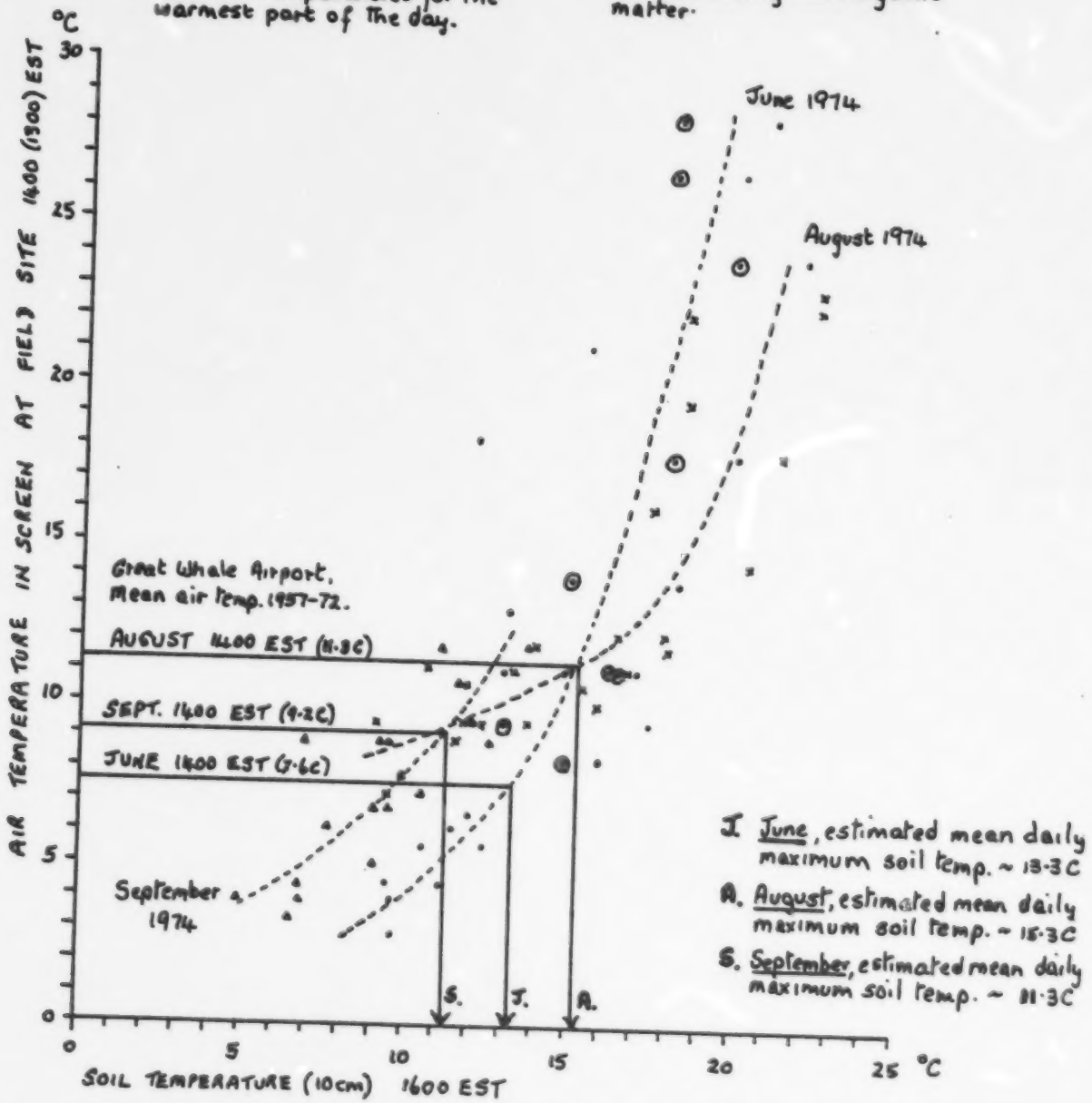
	A	M	J	J	A	S	O	N
pm °C	-1.6	5.3	13.3	16.8	15.3	11.8	6.3	-0.1
°F	29.2	41.5	55.9	62.3	59.5	53.3	43.4	31.9
am °C	-1.6	2.9	10.1	13.6	12.9	9.7	5.2	-0.3
°F	29.2	37.3	50.2	56.5	55.2	49.5	41.4	31.5
mean °C	-1.6	4.1	11.7	15.2	14.1	10.8	5.8	-0.2
°F	29.2	39.4	53.1	59.4	57.4	51.4	42.4	31.7

FIGURE A-4. Great Whale 1974. Air versus soil temperature (10 cm) for a bare "lichen" soil.

• (bare sand)
⊙ bare "lichen" soil, } June.
× bare "lichen" soil, August.
▲ bare "lichen" soil, September.

Air and soil temperatures for the warmest part of the day.

A very favourable site: a sheltered, gentle, south-facing slope, from which the lichen cover had been removed to expose a sandy soil containing dark organic matter.



J. June, estimated mean daily maximum soil temp. ~ 13.3C

A. August, estimated mean daily maximum soil temp. ~ 15.3C

S. September, estimated mean daily maximum soil temp. ~ 11.3C

APPENDIX B

THERMAL INDICES

TABLE B-1. Monthly thermal indices, east coast Hudson/James Bay.

POSTS	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
EM	1800	(0)	(0)	(0)	(0/-I)	(0)	(0)
↓	1801	(+I)	(0/+I)	(0/+I)	(0)	(+I/+II)	(+I)
	1802	(0/-I)	(0)	(0/+I)	(0/+I)	(0/+I)	(-I)
	1803	(-I)	(0)	(0)	(+I)	(0/+I)	(0)
↓	1804	(+I/+II)	(+I/+II)	(0/+I)	(+I)	(+I/+II)	(0)
EM/FG	1805	(0)	(+I)	(0)	(0)	(+I)	(0)
EM/FG	1806	(-I)	(0/+I)	(0/+I)	0	0/-I	-I
EM/FG	1807	-I	-I	0/+I	0/+I	0	-I/-II
EM	1808	-I	0/+I	+I	0/-I	-I	-II
↓	1809	-I	0	+I	+I	0	0/+I
	1810	(-I)	(+I)	(0/+I)	(0/+I)	(+I)	(0/-I)
↓	1811	(+I)	(0/+I)	(0)	(0)	(-I/-II)	(-III)
	1812	(-II/-III)	(-II)	(0/+I)	(0/+I)	(0)	(0/+I)
↓	1813	(0/+I)	(+I)	(0/+I)	(0/+I)	(+I)	(-I/-II)
EM/GW	1814	(-I)	(0)	(0)	(0/-I)	(-I)	-I/-II*
EM/GW	1815	-II*	-II*	0/+I*	(+I)	-I/-II*	-I/-II*
EM/GW-FG	1816	-I/-II*	-II*	-III*	*I/(-III)	(-I)	-II*
EM/FG	1817	-III/-IV*	-III*	-II*	-II*	-II*	-III/-IV*
EM/FG	1818	+I/+II*	0/-I*	0*	0*	0*	0/-I*
EM/FG	1819	0/-I*	-I/-II*	+I*	0/+I*	0/-I*	-II*
EM/FG	1820	-I*	0/+I*	0/+I*	0*	-I/-II*	-I*
EM/FG	1821	-I/-II*	-I*	-I			
EM/FG	1822			(0/-I)	0	0/-I	-I/-II
EM/FG	1823	-II	-I/-II	0/-I	0	-I	-II
EM/FG	1824	-II/-III	(-I/-II)	(0)	(+I)	(0/-I)	(-II)
EM	1825	(-I)	(+I)	(0)	(0/+I	(0)	(-I)
↓	1826	(-I)	(0/+I)	(0)	(0/+I)	(0)	(0/-I)
	1827	(0)	(0/+I)	(-I)	(-I)	(0)	(0/-I)
	1828	(0)	0	+I	0/+I	0/-I	0/-I
	1829	-I	0/-I	0/+I	-I	-I	0/-I
↓	1830	-I/-II	-II	+I	0/-I	-I	0

N.B. For legend, see end of table; for class definitions, see Table 1b.

TABLE B-1. Continued.

POST	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
EM	1831	-I/-II	0				
↓	1832						(-I)
	1833	0	0/-I	0	0	-I	-I
	1834	0/-I	0/-I	0/+I	0	0/-I	-I/-II
	1835	-I	-I/-II	0	0/-I	0/-I	-I
	1836	-II	0/-I	-I	-I/-II	-II	-III
EM-FG	1837	-II	-I/-II	(0)	0/+I	-I	-II
FG	1838	-II	-II	0/+I	-I/-II	-I/-II	-I/-II
	1839	-I	-I	+I	0	-I/-II	-I/-II
	1840	0	-I	+I	+I	0	-I
	1841	0/-I	0/+I	0	+I	0/+I	0
	1842	-II	-II	0	+I	0/-I	-I
	1843	-I/-II	-II	-I/-II	0/-I	-I/-II	-I/-II
	1844	-I	-I	(+I)	(0/+I)	(0/-I)	(-I)
	1845	(-II)	(-I)	(+I)	(0/-I)	(0/-I)	(0)
	1846	(-I)	(+I/+II)	(+I)	(0/+I)	(0/+I)	(0/-I)
	1847	(-II)	(0/+I)	(0)	(0)	(0/-I)	(-I)
	1848	(-I/-II)	(-I)	(0/-I)	(0)	(-I)	(0)
	1849	(-I/-II)	(-II)	(0)	(0)	(-I/-II)	(0/+I)
	1850	(-I)	(+I/+II)	(0/-I	(+I)	(0/+I)	(+I)
	1851	(-I)	(+I)	(0/-I)	(+I)	(0)	(+I)
	1852	(-I/-II)	(-I/-II)	(+I)	(0/+I)	(0/-I)	(0/+I)
	1853	(-II)	(-I/-II)	(0/+I)	(0/-I)	(-I/-II)	(0/-I)
↓	1854	(-I)	(+I)				
	1855						
GW	1856			(0/+I)	(0)	(0)	(0)
FG/GW/LW	1857	-I	0	+I/+II	-I/-II	-I/-II	-I
FG/GW/LW	1858	+I	0/-I	0/+I	-I	-I	0/-I
FG	1859				-I/-II	-I/-II	-II
FG	1860	+II					

TABLE B-1. Continued.

POST	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
	1861						
FG/GW/LW	1862	-I/-II	-I/-II	0/+I	-I	-I/-II	-II
↓	1863	+I	0/-I	0	-I	-I/-II	0/-I
	1864	0	-I	0/+I	0	0/+I	0
	1865	-I/-II	-I/-II	-I	0/-I	-I/-II	-I
FG/LW	1866	-I/-II	-I	-I	-I	(0/-I)	(-I)
FG/LW	1867	0	0/+I	+I	0/+I	-I/-II	0
FG	1868	+I/+II	0	+I	0/-I	(-I)	(-II)
FG	1869	-I/-II	0	0/-I	-I	0/+I	-I
FG/LW	1870	+I/+II	+I/+II	0/+I	0/-I	0/-I	0
FG/LW	1871	-I	-I/-II	-I/-II	-I/-II	-I/-II	-I
LW	1872	-I	+I	-I	(0/+I)	0/+I	0/-I
LW	1873	+I/+II	+I/+II	-I/-II	(+I)	0/+I	-I
FG/LW	1874	-I/-II	0/+I	0/+I	0	0/-I	0
↓	1875	+I	-I	0	+I	-I	-II
	1876	-I	0/+I	0/+I	+I/+II	+I	-I
	1877	+I/+II	0			0	(0)
FG/GW	1878	(+II)	+I	+I/+II	0/+I	+I	0/+I
FG/GW/LW	1879	-I	0/-I	0	0/+I	0	0/-I
FG/GW/LW	1880	0	0/+I	0/+I	0	0	0/+I
GW	1881	+I/+II	0/-I	+I	0	0/-I	-II
FG/LW	1882	0	-I	0	0		0/-I
LW	1883	0	0/-I	(-I)	(0)	(0/-I)	-I
GW/LW	1884	0	-I	(0)	(0/-I)	-I	-II
GW	1885	0/-I	-I	0	(0)	(0)	-I/-II
GW	1886	0/-I	-I	0			
FG/GW/LW	1887	0	(0/+I)	+I	0/+I	0/+I	-I/-II
FG/GW/LW	1888	+I	0	0	-I	-I	-I/-II
FG/LW	1889	0	0/-I	0/+I	+I	0/-I	-I/-II
FG/GW/LW	1890	-I/-II	0/+I	0/-I	0/-I	0	+I

TABLE B-1. Continued.

POST	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
FG/GW	1891	-I/-II	0/-I	0/-I	0/-I	-I	-I
FG/GW	1892	0/-I	0/+I	0/+I	0/+I	0	0
EM/FG/GW	1893	0	+II	0	+I/+II	0/+I	0
↓	1894	-I	+I/+II	0/+I	0/-I	0/+I	0
	1895	-I	0/+I	0/+I	0/+I	0	-I/-II
	1896	+I	0/-I	0/+I	+I	-I/-II	-I/-II
	1897	-I/-II	0	+I/+I	0	0	0/-I
	1898	0	-I	0/+I	0/+I	0/+I	-I
	1899	0/-I	0/-I	0/+I	0	-I	0
	1900	-I	-I	0/+I	0/+I	0/-I	0

N.B. Degree of confidence: 0* Based on temperature records, Journal daily weather reports and proxy information.
0 Based on regular daily weather reports in Journals and proxy information.
(0) Based on intermittent weather reports of varying quantity, and proxy information.

NORMAL REFERENCE TEMPERATURES, °C.

STATION	YEARS	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
Great Whale	1941-70	0.9	6.3	10.6	10.3	7.5	2.3
Fort George	1941-70	2.5	8.8	12.4	11.2	8.1	2.9
Eastmain	1960-72	4.1	10.6	13.2	12.2	9.6	4.7
	(1951-80)	(5.1)	(11.3)	(13.7)	(13.0)	(9.2)	(3.8)

TABLE B-2. Monthly thermal indices, Great Whale (1926-1985), Fort George (1916-1925).

YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
1916	+I	+I/+II	+I/+II	+I/+II	0	
1917	0/-I	+I	+I/+II	0/+I		-I
1918	-I/-II	-I/-II	0/-I	-I	-I/-II	-I
1919	+I	+I	0/+I	+I/+II	0/-I	-I/-II
1920	+II	+I	-I	+I		
1921	+I		+I/+II	0/-I	0	
1922						
1923	0/-I	-I	0/-I	-I		0/+I
1924	0	0/-I		0/-I		0/+I
1925	-I	-I	-I/-II	0/+I		
1926	-I/-II	0/-I	-I/-II	-I	0	0
1927	0/+I	0/-I	0/-I	-I	0/+I	0/+I
1928	+I/+II	0	0/-I	0/+I	0/-I	0/-I
1929	-I	0	-II	0/-I	-I	0/-I
1930	0/+I	+I/+II	0/-I	+I/+II	+I	+I
1931	-I	0/+I	+II	+I	0	0/+I
1932	-I/-II	-I	-I/-II	0/+I	0	-I
1933	-I/-II	-I	0/-I	0	0/+I	0/-I
1934	-I/-II	0/-I	-I	-I/-II	0	0/-I
1935	0	+I/+II	0/+I	+I/+II	0	0/-I
1936	-II	-I/-II	0	0/-I	0/-I	-II
1937	0/+I	+I/+II	0	+I	0/-I	0/+I
1938	+I	0/+I	0/+I	0/+I	0/+I	+I
1939	0/-I	0	0/-I	+I	0/-I	-I/-II
1940	0	0	0/-I	0/+I	+I	0/-I

N.B For class definitions, see Table 1b.

TABLE B-2. Continued.

YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
1941	0/+I	0	0/+I	0	0/-I	0/-I
1942	0/-I	+I	0/-I	0	0/-I	0
1943	0	-I/-II	0	0	0/+I	0/+I
1944	0/-I	0/-I	0/+I	+I	0/+I	0/-I
1945	0	0	0/-I	0/-I	-I	0/-I
1946	-I	-I	-I/-II	-I	0/-I	0/-I
1947	-I/-I	0/+I	-I	-I	-I	+I
1948	0/+I	0/+I	+I/+II	+I	+I	+I/+II
1949	0	+I/+II	0/-I	0/-I	0	0
1950	0/+I	-I	-I/-II	0/-I	0/-I	0/-I
1951	+I	+I	0/-I	0	0	0/-I
1952	+I/+II	0	0/+I	0/+I	0/-I	-I
1953	0/-I	0/-I	0	0/-I	0/-I	0
1954	+I	+I/+III	+I	+I	0/+I	0
1955	+I	+IV	+I	+I/+II	0	+I/+II
1956	-II/-III	-I	0/+I	0/+I	0/-I	0
1957	-I/-II	0/+I	0/+I	-I	0	0/+I
1958	0	0	0/-I	0/-I	0/-I	0/-I
1959	0	0	0/+I	0	0/+I	-I
1960	+II	0/+I	0/+I	0/+I	0	0
1961	0	-I/-II	0/-I	0	0/+I	0
1962	0	0/-I	0/+I	0	0	0/+I
1963	0/-I	0/-I	0/+I	-I	-I	0/+I
1964	+I	-I	0	0	0/-I	-I
1965	0	0	-II	-I/-II	-I/-II	-I
1966	0	0/+I	0	0/+I	0/+I	0/-I
1967	0	+I	0	0	0	0
1968	+I/+II	+I	0/-I	0/-I	+III	+I/+II
1969	-I	-I/-II	0	0/+I	-I/-II	-I
1970	-I	-I	0	0/+I	0/+I	+I

TABLE B-2. Continued.

YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
1971	0/-I	0/-I	-I	-I	0	+I
1972	-I/-II	0/-I	0/-I	-I	-I	-I/-II
1973	+I	0/+I	0	+I	0/+I	+I
1974	0/+I	+II	+I	0/+I	-I/-II	-I/-II
1975	+II	+II	0	0/+I	0	0/+I
1976	0/-I	0	0/+I	0	0/-I	0/-I
1977	0	0/+I	-I	0/+I	0	+I
1978	0	-I	0	0/-I	-I	-I
1979	0/+I	0/+I	0/-I	0/-I	0/-I	-I
1980	+I	-I	0	+II	-I	-I
1981	-I	-I	0	+I/+II	0/+I	0
1982	+I/+II	(0/-I)	0/-I	0/-I	0/+I	0/+I
1983	0/-I	+I/+II	-I	0/+I	0/+I	0
1984	0	0	0/-I	0/+I	0/-I	0/+I
1985	-I	+II	-II	+I	0/+I	-III

( ) Eastmain

NORMAL REFERENCE TEMPERATURES, °C.

Station	Years	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
GW	1941-70	0.9	6.3	10.6	10.3	7.5	2.3
FG	1941-70	2.5	8.8	12.4	11.2	8.1	2.9

TABLE B-3a. Reconstructed seasonal temperature anomalies, °C.
May to October, east coast Hudson / James Bay.

YEAR	0	1	2	3	4	5	6	7	8	9
1800	-0·2	+1·5	0·0	+0·2	+2·0	+0·7	-0·5	-0·8	-1·0	+0·5
1810	+0·5	-1·0	-1·0	+0·7	-1·3	-1·8	-4·0	-5·3	+0·2	-1·0
1820	-0·8			-2·3	-1·8	-0·2	-0·2	-0·7	+0·2	-1·2
1830	-1·3			-0·8	-0·8	-1·5	-3·3	-2·0	-2·7	-1·3
1840	0·0	+0·5	-1·5	-2·8	-0·7	-1·0	+0·7	-1·0	-1·8	-1·5
1850	+0·8	+0·5	-0·5	-1·8				-1·2	-0·5	
1860			-2·3	-0·8	0·0	-2·8	-2·0	+0·2	-0·3	-1·2
1870	+0·8	-2·7	-0·2	+0·7	-0·8	-0·7	+0·5		+2·2	-0·5
1880	+0·5	-0·2		-1·0	-1·5	-1·0		+0·3	-0·8	-0·3
1890	-0·3	-1·7	+0·8	+1·3	+0·3	-0·3	-0·3	-0·2	-0·2	-0·5
1900	-0·5									

With reference to the 1941-1970 normal.

TABLE B-3b. Seasonal temperature anomalies, °C, May to October.
Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910									-2·3*	+0·7*
1920							-1·5	-0·2	+0·2	-1·7
1930	+1·7	+1·0	-1·5	-1·0	-1·7	+1·0	-2·2	+1·0	+1·3	-0·7
1940	+0·2	0·0	-0·2	-0·2	+0·2	-0·8	-1·8	-1·0	+2·0	+0·2
1950	-1·2	+0·3	+0·3	-0·7	+1·7	+3·0	-1·0	-0·3	-0·7	0·0
1960	+1·2	-0·5	+0·2	-0·7	-0·5	-2·0	+0·3	+0·3	+2·0	-1·5
1970	0·0	-0·7	-2·0	+1·7	+0,3	+1·7	-0·3	+0·3	-1·2	-0·5
1980	0·0	0·0	+0·3	+0·3	0·0	-1·2				

1941-1970 normal temperature, Great Whale: 6·3C.
Fort George: 7·7C

TABLE B-4a. Reconstructed spring temperature anomalies, °C, May/June, east coast Hudson/James Bay.

YEAR	0	1	2	3	4	5	6	7	8	9
1800	0.0	+1.5	-0.5	-1.0	+3.0	+1.0	-0.5	-2.0	-0.5	-1.0
1810	0.0	+1.5	-4.5	+1.5	-1.0	-4.0	-3.5	-6.5	+1.0	-2.0
1820	-0.5	-2.5		-3.5	-4.0	0.0	-0.5	+0.5	0.0	-1.5
1830	-3.5	-1.5		-0.5	-1.0	-2.5	-2.5	-3.5	-4.0	-2.0
1840	-1.0	0.0	-4.0	-3.5	-2.0	-3.0	+0.5	-1.5	-2.5	-3.5
1850	+0.5	0.0	-3.0	-3.5	0.0			-7.0	+0.5	
1860			-3.0	+0.5	-1.0	-3.0	-2.5	+0.5	+1.5	-1.5
1870	+3.0	-2.5	0.0	+3.0	-1.0	0.0	-0.5	+1.5	+3.0	-1.5
1880	+0.5	+1.0	-1.0	-0.5	-1.0	-1.5	-1.5	+0.5	+1.0	-0.5
1890	-1.0	-2.0	0.0	+2.0	+0.5	-0.5	+0.5	-1.5	-1.0	-1.0
1900	-2.0									

TABLE B-4b. Spring temperature anomalies, °C, May/June, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910							+2.5*	+0.5*	-3.0*	+2.0*
1920	+3.0*			-1.5*	-0.5*	-2.0*	-2.0	0.0	+1.5	-1.0
1930	+2.0	-0.5	-2.5	-2.5	-2.0	+1.5	-3.5	+2.0	+1.5	-0.5
1940	0.0	+0.5	+0.5	-1.5	-1.0	0.0	-2.0	-1.0	+1.0	+1.5
1950	-0.5	+2.0	+1.5	-1.0	+2.5	+5.0	-3.5	-1.0	0.0	0.0
1960	+2.5	-1.5	-0.5	-1.0	0.0	0.0	+0.5	+1.0	+2.5	-2.5
1970	-2.0	-1.0	-2.0	+1.5	+2.5	+4.0	-0.5	+0.5	-1.0	+1.0
1980	0.0	-2.0	+1.0	+1.0	0.0	+1.0				

1941-1970 normal temperature, Great Whale: 3.6C.
Fort George: 5.7C.

TABLE B-5a. Reconstructed mid-summer temperature anomalies, °C, July/August, east coast Hudson/James Bay.

YEAR	0	1	2	3	4	5	6	7	8	9
1800	-0.5	+0.5	+1.0	+1.0	+1.5	0.0	+0.5	+1.0	+0.5	+2.0
1810	+1.0	0.0	+1.0	+1.0	-0.5	+1.5	-5.5	-4.0	0.0	+1.5
1820	+0.5		-0.5	-0.5	+1.0	+0.5	+0.5	-2.0	+1.5	-0.5
1830	+0.5			0.0	+0.5	-0.5	-2.5	+0.5	-1.0	+1.0
1840	+2.0	+1.0	+1.0	-2.0	+1.5	+0.5	+1.5	0.0	-0.5	0.0
1850	+0.5	+0.5	+1.5	0.0			+0.5	0.0	-0.5	
1860			-0.5	-1.0	+0.5	-1.5	-2.0	+1.5	+0.5	-1.5
1870	0.0	-3.0	-0.5	-0.5	+0.5	+1.0	+2.0		+2.0	+0.5
1880	+0.5	+1.0	0.0	-1.0	-0.5	0.0		+1.5	-1.0	+1.5
1890	-1.0	-1.0	+1.0	+1.5	0.0	+1.0	+1.5	+1.5	+1.0	+0.5
1900	+1.0									

TABLE B-5b. Mid-summer temperature anomalies, °C, July/August, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910							+3.0*	+2.0*	-1.5*	+2.0*
1920	0.0*	+1.0*		-1.5*		-1.0*	-2.5	-1.5	0.0	-2.5
1930	+1.0	+3.0	-1.0	-0.5	-2.5	+2.0	-0.5	+1.0	+1.0	+0.5
1940	0.0	+0.5	-0.5	0.0	+1.5	-1.0	-2.5	-2.0	+2.5	-1.0
1950	-2.0	-0.5	+1.0	-0.5	+2.0	+2.5	+1.0	-0.5	-1.0	+0.5
1960	+1.0	-0.5	+0.5	-0.5	0.0	-3.5	+0.5	0.0	-1.0	+0.5
1970	+0.5	-2.0	-1.5	+2.0	+1.5	+0.5	+0.5	-0.5	-0.5	-1.0
1980	+2.0	+1.5	-1.0	-0.5	0.0	-1.0				

1941-1970 normal temperature, Great Whale: 10.5C.
Fort George: 11.8C.

TABLE B-6a. Reconstructed autumn temperature anomalies, °C, September/October, east coast Hudson/James Bay.

YEAR	0	1	2	3	4	5	6	7	8	9
1800	0.0	+2.5	-0.5	+0.5	+1.5	+1.0	-1.5	-1.5	-3.0	+0.5
1810	+0.5	-4.5	+0.5	-0.5	-2.5	-3.0	-3.0	-5.5	-0.5	-2.5
1820	-2.5		-2.0	-3.0	-2.5	-1.0	-0.5	-0.5	-1.0	-1.5
1830	-1.0			-2.0	-2.0	-1.5	-5.0	-3.0	-3.0	-3.0
1840	-1.0	+0.5	-1.5	-3.0	-1.5	-0.5	0.0	-1.5	-1.0	-1.0
1850	+1.5	+1.0	0.0	-2.0			0.0	-2.5	-1.5	-3.5
1860			-3.5	-2.0	+0.5	-2.5	-1.5	-1.5	-3.0	-0.5
1870	-0.5	-2.5	0.0	-0.5	-0.5	-3.0	0.0	0.0	+1.5	-0.5
1880	+0.5	-2.5		-1.5	-3.0	-1.5		-1.0	-2.5	-2.0
1890	+1.0	-2.0	0.0	+0.5	+0.5	-1.5	-3.0	-0.5	-0.5	-1.0
1900	-0.5									

TABLE B-6b. Autumn temperature anomalies, °C, September/October, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910									-2.5*	-2.0*
1920							0.0	+1.0	-1.0	-1.5
1930	+2.0	+0.5	-1.0	0.0	-0.5	-0.5	-2.5	0.0	+1.5	-2.0
1940	+0.5	-1.0	-0.5	+1.0	0.0	-1.5	-1.0	0.0	+2.5	0.0
1950	-1.0	-0.5	-1.5	-0.5	+0.5	+1.5	-0.5	+0.5	-1.0	-0.5
1960	0.0	+0.5	+0.5	-0.5	-1.5	-2.5	0.0	0.0	+4.5	-2.5
1970	+1.5	+1.0	-2.5	+1.5	-3.0	+0.5	-1.0	+1.0	-2.0	-1.5
1980	-2.0	+0.5	+1.0	+0.5	0.0	-3.5				

1941-1970 normal temperature, Great Whale: 4.9C.
Fort George: 5.5C.

FIGURE B-1. East coast Hudson/James Bay. Reconstructed temperature anomalies, °C, June - August, 1800 to 1900.

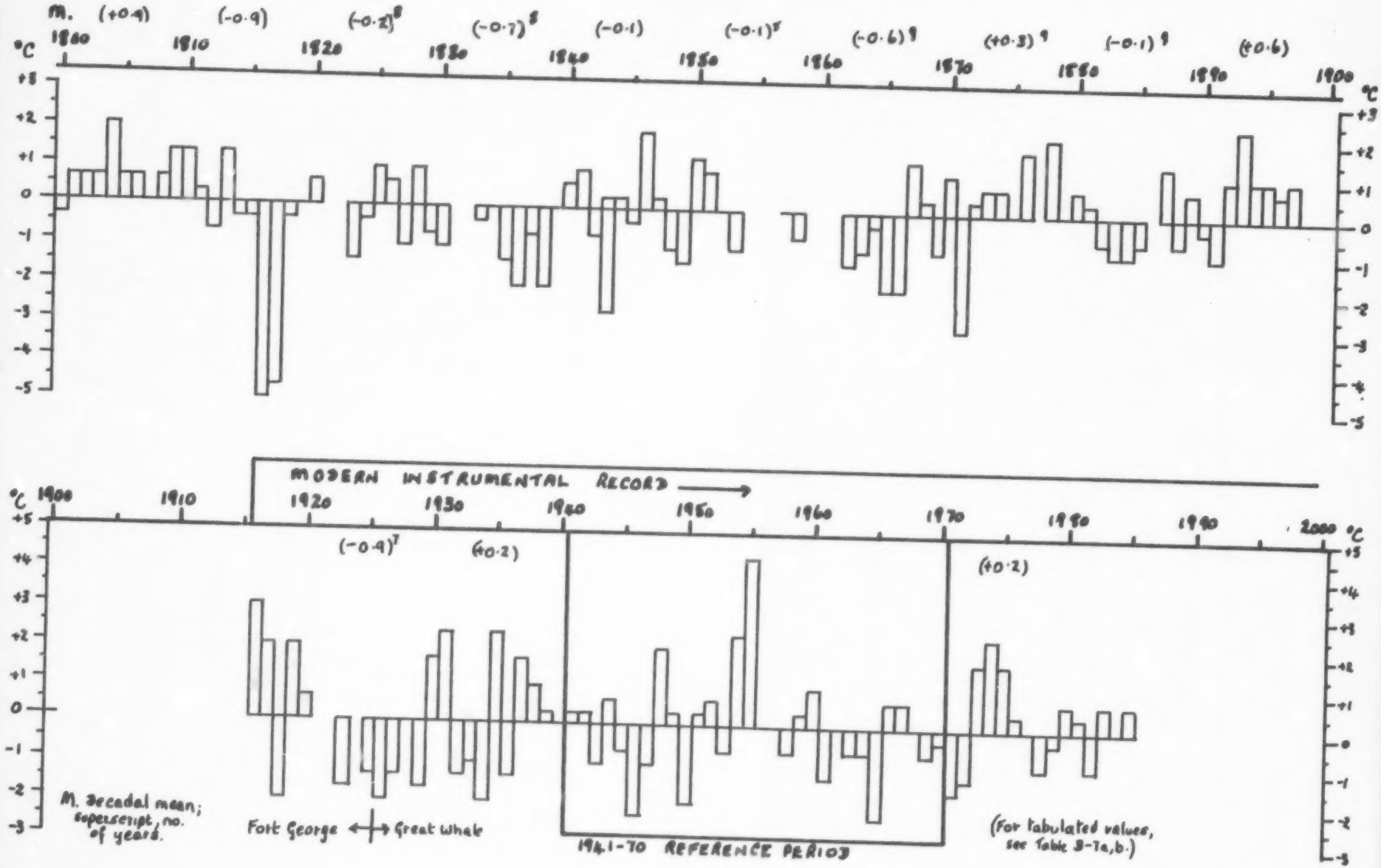


TABLE B-7a. Reconstructed temperature anomalies, °C, June-August, east coast Hudson/James Bay.

YEAR	0	1	2	3	4	5	6	7	8	9
1800	-0.3	+0.7	+0.7	+0.7	+2.0	+0.7	+0.7	0.0	+0.7	+1.3
1810	+1.3	+0.3	-0.7	+1.3	-0.3	-0.3	-5.0	-4.7	-0.3	0.0
1820	+0.7			-1.3	-0.3	+1.0	+0.7	-1.0	+1.0	-0.7
1830	-1.0			-0.3	0.0	-1.3	-2.0	-0.7	-2.0	0.0
1840	+0.7	+1.0	-0.7	-2.7	+0.3	-0.3	+2.0	+0.3	-1.0	-1.3
1850	+1.3	+1.0	0.0	-1.0				0.0	-0.7	
1860			-1.3	-1.0	-0.3	-2.0	-2.0	+1.3	+0.3	-1.0
1870	+1.0	-3.0	+0.3	+0.7	+0.7	0.0	+1.7		+2.0	0.0
1880	+0.7	+0.3	-0.7	-0.0	-1.0	-0.7		+1.3	-0.7	+0.7
1890	-0.3	-1.0	+1.0	+2.3	+1.0	+1.0	+0.7	+1.0	0.0	0.0
1900	0.0									

TABLE B-7b. June-August temperature anomalies, °C, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910							+3.0*	+2.0*	-2.0*	+2.0*
1920	+0.7*			-1.7*		-1.3*	-2.0	-1.3	0.0	-1.7
1930	+1.7	+2.3	-1.3	-1.0	-2.0	+2.3	-1.3	+1.7	+1.0	+0.3
1940	0.0	+0.3	+0.3	-1.0	+0.7	-0.7	-2.3	-1.0	+2.0	+0.3
1950	-2.0	+0.3	+0.7	-0.7	+2.3	+4.3	0.0	0.0	-0.7	+0.3
1960	+1.0	-1.3	0.0	-0.7	-0.7	-2.3	+0.7	+0.7	0.0	-0.7
1970	-0.3	-1.7	-1.3	+1.7	+2.3	+1.7	+0.3	0.0	-1.0	-0.3
1980	+0.7	+0.3	-1.0	+0.7	0.0	+0.7				

1941-1970 normal temperature, Great Whale: 9.1 C.
Fort George: 10.8C.

APPENDIX C

WETNESS INDICES

TABLE C - 1. Monthly wetness indices, east coast Hudson/James Bay.
(Index from +2, Very Wet to - 2, Very Dry.)

POST	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
EM	1800				(W)		
↓	1801						
	1802						
	1803					(W)	(O)
↓	1804					(D)	
EM/FC	1805		(D)			(D)	
EM/FC	1806		(O)		W	VD	D
EM/FC	1807	VD	O	VD	O	VD	D
EM	1808	VW	O	D	O	O	VW
↓	1809	VD	D	D	VD	VD	D
	1810		(VD)				
↓	1811	(D)	(VD)	(D)	(D)	(O)	(W)
	1812						
↓	1813			(O)	(W)	(D)	
EM/GW	1814		(O)		(W)	(W)	VW*
EM/GW	1815	W*	VW*	D*	(O)	D*	VW*
EM/GW-FC	1816	VW*	VW*	O*	VW*	(O)	VW*
EM/FC	1817	VW*	VW*	W*	W*	VW*	W*
↓	1818	O*	VW*	VW*	O*	D*	O*
	1819	D*	VW*	O*	O*	O*	VW*
	1820	VW*	VW*	VW*	W*	W*	O*
↓	1821	O*	D*	D			
	1822				O	D	D
	1823	O	D	D	O	O	O
↓	1824	O			(O)		
EM	1825	(D)	(O)	(O)	(D)	(D)	(O)
↓	1826			(O)	(O)		
	1827			(W)	(W)		
	1828	(O)	O	D	O	O	O
	1829	O	O	W	VW	O	O
↓	1830	VW	O	W	W	O	O

N.B. For legend, see end of table.

TABLE C -1. Continued.

POST	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
EM	1831	VW	W				
↓	1832						(O)
	1833	D	O	O	W	W	W
	1834	O	O	W	O	VD	O
	1835	W	O	VD	O	D	O
	1836	VD	O	O	W	O	D
EM-FG	1837	O	VD	(D)	W	W	W
FG	1838	VW	O	O	O	O	O
	1839	VW	W	O	O	W	O
	1840	O	O	D	W	D	W
	1841	O	O	O	VW	D	W
	1842	VW	VW	W	O	O	W
	1843	VW	W	VW	O	O	VW
	1844	VW	O	(D)	O	D	O
	1845	VW	W	(D)	(O)	(O)	(D)
	1846	(D)	(D)	(D)	(O)	(O)	(O)
	1847	(O)	(O)	(D)	(D)	(O)	(O)
	1848	(D)	(O)	(O)	(O)	(D)	(O)
	1849	(O)	(O)	(O)	(O)	(W)	(D)
	1850	(O)	(D)	(O)	(D)	(W)	(D)
	1851	(D)	(O)	(O)	(O)	(W)	(O)
	1852	(D)	(VD)	(D)	(D)	(O)	(D)
	1853	(O)	(O)	(D)	(O)	(O)	(D)
↓	1854	(D)	(D)				
	1855						
GW	1856			(D)		(D)	
FG/GW/LW	1857	W	W	VD	O	W	O
FG/GW/LW	1858	O	W	D	O	W	O
FG	1859				O	O	VW
FG	1860	O					

TABLE C-1. Continued.

POST	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
	1861						
FG/GW/LW	1862	O	O	O	VW	O	VW
↓	1863	D	D	D	W	O	O
	1864	O	W	D	O	D	VD
↓	1865	O	O	D	O	O	D
FG/LW	1866	W	O	VD	D	D	VD
FG/LW	1867	O	O	D	D	VW	D
FG	1868	VD	O	O	W	(W)	(O)
FG	1869	O	D	O	W	D	O
FG/LW	1870	VD	O	D	O	O	D
FG/LW	1871	W	O	O	W	W	W
LW	1872	D	O	O	(D)	(VD)	O
LW	1873	VD	O	VW	(VD)	D	O
FG/LW	1874	D	W	W	D	W	O
↓	1875	O	W	O	(VD)	O	D
	1876	O	O	O	VD	(D)	O
↓	1877	O	O			D	
FG/GW	1878	(O)	VD	VD	O	VD	D
FG/GW/LW	1879	O	O	D	VD	O	O
FG/GW/LW	1880	O	W	D	VD	(VD)	VD
GW	1881	O	D	D	VD	(W)	VW
FG/LW	1882	W	O	D	W	(O)	(O)
LW	1883	W	O	(O)	(D)	(O)	D
GW/LW	1894	O	D	(O)	(O)	D	W
GW	1885	D	VW	O	(D)	VD	VW
GW	1886	W	O	(O)			
FG/GW/LW	1887	D	(D)	D	D	O	W
FG/GW/LW	1888	O	D	O	O	O	O
FG/LW	1889	O	W	D	D	O	VW
FG/GW/LW	1890	O	O	D	D	VD	VD

TABLE C-1. Continued.

POST	YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
FG/GW	1891	W	O	D	D	D	W
FG/GW	1892	D	O	D	D	D	O
EM/FG/GW	1893	D	VD	O	O	D	O
↓	1894	O	D	O	D	D	D
	1895	O	O	O	O	O	VW
	1896	O	O	D	O	O	O
	1897	O	O	VD	O	VD	O
	1898	O	O	O	D	VD	O
	1899	D	O	D	W	VW	O
	1900	O	O	VD	D	O	D

N.B. Degree of confidence: O" Based on weather diaries (with two to three observations a day), Journal weather and proxy data.
O Based on regular daily weather reports in Journals and proxy information.
(O) Based on intermittent weather reports of varying quantity, and proxy information.

MODERN REFERENCE DATA.

STATION		YEARS	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	SEASON
Great Whale	a)	1941-70	14	11	15	16	18	18	92
	b)	1926-76	9 — 26	9 — 15	12 — 17	15 — 18	15 — 20	16 — 21	79 — 100
Fort George	a)	1941-70	7	7	10	11	12	12	59
	b)	1916-69	4 — 9	5 — 10	7 — 12	8 — 14	9 — 14	9 — 16	50 — 76
Eastmain	a)	1960-72	9	9	13	13	17	15	76
	b)	1960-76	8 — 11	8 — 11	11 — 15	10 — 15	15 — 18	13 — 18	68 — 81

a) Mean number of days with measurable precipitation.
b) Limits to class "O".

TABLE C-2. Monthly wetness indices, Great Whale (Fort George*).
(Index from +2, Very Wet to -2, Very Dry.)

YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
1916	VW*	VW*	O*	O*	W*	D*
1917		O*	O*	W*	O*	VD*
1918			O*	O*	O*	
1919	VD*	D*	O*	VD*	D*	
1920	VD*	VD*	O*	D*	VD*	D*
1921	O*	D*	VD*	O*	O*	VD*
1922	VD*	VD*	D*	O*	O*	
1923			VD*	D*	VD*	O*
1924	O*	D*	VD*	O*	D*	VD*
1925		VD*	O*	VD*		VD*
1926		O	W	O	VD	
1927		VW	VD	O	O	
1928		VD	VD	O	D	
1929		D	VW	O	O	
1930		D	VW	O	O	
1931		W	O	VW	VD	
1932		O	O	VD	VW	
1933	VD*	W*	D	O	O	O
1934	O	O	W	VW	W	O
1935	VD	O	O	O	O	D
1936	D	W	VD	O	O	D
1937	D	O	D	O	W	O
1938	O*	W*	O*	VW*	VW*	W*
1939	VW*	O*	VW*	O*	W	O
1940	O*	VW*	O	O	D	O

TABLE C-2. Continued.

YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
1941	D	VD	D	W*	O	O
1942	O	O	VW	VW	O	O
1943	O	O	O	VW	VW	D
1944	W	VW	W	W	W	VW
1945	O					
1946						O
1947	VW	O				
1948	O	D	O	VD	O	D
1949	D	O	VW	VD	O	VW
1950	O	W	O	O*	D	O
1951	O	O	W	O	VW*	D
1952	O	O	O	O	O	O
1953	D	O	O	D	VW	O
1954	O*	O*E	O*	O*	O*	O*
1955	O	D	O	D	W	O
1956	VW	VD	D*	W*	O*	O*
1957	W	W	O	W	O	W
1958	W	O	VD	O	O	D
1959	W	O	O	D	O	VW
1960	D	VW	O	W	O	VW
1961	O	O	VD	D	O	D
1962	VD	O	D	D	O	D
1963	O	VD	O	O	O	VD
1964	O	W	VD	O	VW	O
1965	VW	O	VW	W	VW	O
1966	O	W	D	D	O	W
1967	W	O	O	W	D	O
1968	O	O	O	VD	D	O
1969	VW	W	O	O	VD	VW
1970	O	D	O	O	O	VD

E. Estimate.

TABLE C-2. Continued.

YEAR	MAY	JUNE	JULY	AUG.	SEPT.	OCT.
1971	O	O	VW	O	O	O
1972	VD	O	O	W	O	O
1973	O	O	D	VD	O	W
1974	O	W	O	O	VW	W
1975	O	O	O	O	O	O
1976	W	O	O	O	D	VW
1977	D	O	VW	VW	VD	W
1978	O	O	O	VW	O	VW
1979	W	O	W	W		
1980	O	O	O	W	O	O
1981	O	O	O	D	O	O
1982	D	(VW)	O	D	O	O
1983	O	O	O	D	W	W
1984	D	D	O	VD	W	D
1985	D	O	VD	D	D	VD

( )Eastmain

MODERN REFERENCE DATA — The mean and the range

NUMBER OF DAYS WITH MEASURABLE PRECIPITATION (≥0.2mm).

STATION	YEARS	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	SEASON
Great Whale	1941-70 All record	4 14 22	2 11 18	4 15 21	7 16 23	10 18 24	10 18 27	63 92 123
Fort George	1941-70 All record	1 7 13	2 7 17	2 10 17	5 11 17	6 12 22	0 12 25	31 59 82
Eastmain	1960-72 All record	4 9 16	5 9 13	6 13 19	8 15 19	9 17 20	9 15 20	62 76 92

TOTAL PRECIPITATION (mm.)

Great Whale	1941-70 All record	8 44 94	8 49 109	8 82 189	28 92 193	32 84 150	32 68 155	419
Fort George	1941-70 All record	3 35 82	9 50 104	8 83 288	12 68 143	17 69 119	9 68 131	373
Eastmain	1960-72 All record	5 53 81	18 71 124	33 80 138	37 71 107	57 84 129	43 61 138	421

TABLE C-3a. Seasonal wetness indices, May to October, east coast Hudson/James Bay. (Index from +2, Very Wet to -2, Very Dry.)

YEAR	0	1	2	3	4	5	6	7	8	9
1800	(0)	(0)	(0)	(0)	(0)	(0)	(0)	VD	W	VD
1810	(0)	(0)	(0)	(0)	(W)	W	VW	VW	W	W
1820	VW		(0)	0	(0)	(D)	(0)	(W)	(0)	W
1830	W		(0)	W	0	D	0	0	0	W
1840	0	W	VW	VW	0	(0)	(D)	(0)	(0)	(0)
1850	(D)	(0)	(VD)	(D)				0	0	(0)
1860			W	0	D	0	VD	0	0	0
1870	D	W	VD	D	0	0	D		(VD)	0
1880	VD	0	(0)	(0)	(0)	0		D	0	0
1890	VD	0	D	VD	D	0	0	D	D	0
1900	D									

( ) See legend Table C-1.

TABLE C-3b. Wetness indices, May to October, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910							0*			
1920	VD*	D*			VD*					
1930					W	0	D	0	W*	VW*
1940	W*	0*	W	0	VW				VD	0
1950	(0)	(0)	0	D	0*	0	0*	VW	0	W
1960	W	VD	VD	D	0	VW	0	0	0	W
1970	D	0	0	D	VW	0	0	W	W	
1980	0	0	0	0	D	VD				

( ) 1 month FG.

TABLE C-4a. Spring wetness indices, May/June, east coast Hudson/James Bay. (Index from +4, VW to -4, VD.)[1]

YEAR	0	1	2	3	4	5	6	7	8	9
1800								-2	+2	-3
1810		-3				+3	+4	+4	+2	+1
1820	+4	-1		-1		(-1)			(0)	0
1830	+2	+3		-1	0	+1	-2	-2	+2	+3
1840	0	0	+4	+3	+2	+3	(-2)	(0)	(-1)	(0)
1850	(-1)	(-1)	(-3)	(0)	-2			+2	+1	
1860			0	-2	+1	0	+1	0	-2	-1
1870	-2	+1	-1	-2	0	+1	0	0	(-2)	0
1880	+1	-1	+1	+1	0	+1	+1	(-2)	-1	+1
1890	0	+1	-1	-3	-1	0	0	0	0	-1
1900	0									

( ) See legend Table C-1.

TABLE C-4b. Spring wetness indices, May/June, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910							+4*			-3*
1920	-4*	-1*	-4*		-1*					
1930				-1*	0	-2	0	-1	+1*	+2*
1940	+2*	-3	0	0	+3			+2	-1	-1
1950	+1	0	0	-1		-1	0	+2	+1	+1
1960	+1	0	-2	-2	+1	+2	+1	+1	0	+3
1970	-1	0	-2	0	+1	0	+1	-1	0	+1
1980	0	0		0	-2	-1				

1. These bimonthly values are the sum of the 2 monthly indices.

TABLE C-5a. Mid-summer wetness indices, July/August, east coast Hudson/James Bay. (Index from +4, VW to -4, VD.)[1]

YEAR	0	1	2	3	4	5	6	7	8	9
1800								-2	-1	-3
1810		-2		+1		-1	+2	+2	+2	0
1820	+3			-1		(-1)	(0)	(+2)	-1	+3
1830	+2			+1	+1	-2	+1	0	0	0
1840	0	+2	+1	+2	-1	(-1)	(-1)	(-2)	(0)	(0)
1850	(-1)	(0)	(-2)	(-1)				-2	-1	
1860			+2	0	-1	-1	-3	-2	+1	+1
1870	-1	+1	(-1)	(0)	0	(-2)	-2		-2	-3
1880	-3	-3	0	(-1)	(0)	(-1)		-2	0	-2
1890	-2	-2	-2	0	-1	0	-1	-2	-1	0
1900	-3									

( ) See legend Table C-1.

TABLE C-5b. Mid-summer wetness indices, July/August, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910							0*	+1*	0*	-2*
1920	-1*	-2*	-1*	-3*	-2*	-2*	+1	-2	-2	+2
1930	+2	+2	-2	-1	+3	0	-2	-1	+2*	+2*
1940	0	(0)	+4	+2	+2				-2	0
1950	(0)	+1	0	-1	0*	-1	0*	+1	-2	-1
1960	+1	-3	-2	0	-2	+3	-2	+1	-2	0
1970	0	+2	+1	-3	0	0	0	+4	+2	+2
1980	+1	-1	-1	-1	-2	-3				

( ) 1 month FG.

1 These bimonthly values are the sum of the 2 monthly indices.

TABLE C-6a. Autumn wetness indices, September/October, east coast Hudson/James Bay. (Index from +4, VW to -4, VD.)[1]

YEAR	0	1	2	3	4	5	6	7	8	9
1900				+1			-3	-3	+2	-3
1910		+1			+3	+1	+2	+3	-1	+2
1920	+1		-2	0		(-1)			0	0
1930	0			+2	-2	-1	-1	+2	0	+1
1940	0	0	+1	+2	-1	(-1)	(0)	(0)	(-1)	(0)
1950	(0)	(+1)	(-1)	(-1)				+1	+1	+2
1960			+2	0	-3	-1	-3	+1	(+1)	-1
1970	-1	+2	(-2)	-1	+1	-1	(-1)		-3	0
1980	(-4)	(+3)	(0)	-1	0	0		+1	0	+2
1990	-4	0	-1	-1	-2	+2	0	-2	-2	+2
2000	-1									

( ) See legend Table C-1.

TABLE C-6b. Autumn wetness indices, September/October, Great Whale (Fort George*).

YEAR	0	1	2	3	4	5	6	7	8	9
1910							0*	-2*		
1920	-3*	-2*		-2*	-3*					
1930				0	+1	-1	-1	+1	+3*	+1
1940	-1	0	0	+1	+3				-1	+2
1950	-1	(+1)	0	-2	0*	+1	0*	+1	-1	+2
1960	+2	-1	-1	-2	+2	+2	+1	-1	-1	0
1970	-2	0	0	+1	+3	0	+1	-1	+2	
1980	0	0	0	+2	0	-3				

( ) 1 month FG.

[1] These bimonthly values are the sum of the 2 monthly indices.